51 58
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69 71

INFRARED REMOTE CONTROL EXTENDER
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GO ANYWHERE ELECTRONICS!
HEAT, DAMP, IMPACT HOW TO SURVIVE IT

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TWO TIER ALARM IS YOUR TIME-REMINDER

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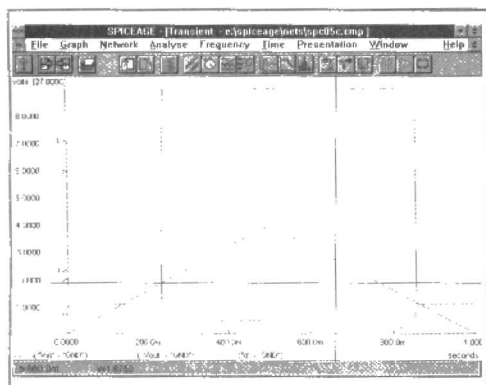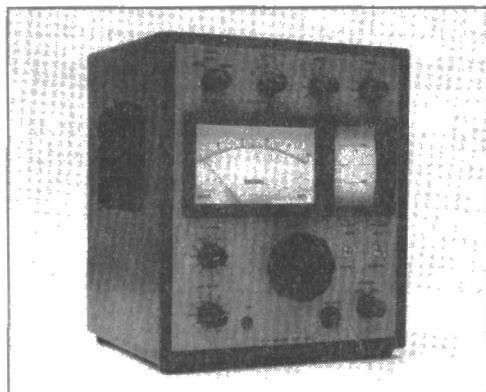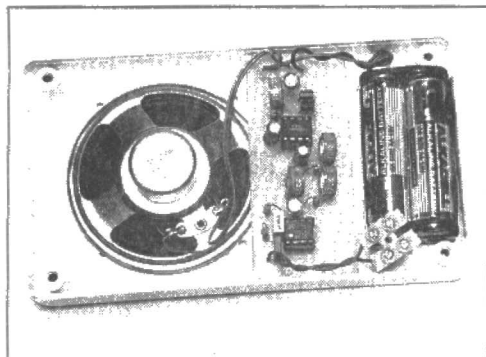### DEDICATED TO SIFTING OUT MEDIUM WAVE STATIONS

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& Features & Projects

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Regulars

Young Radio Amateur of the Year

The Young Radio Amateur of the Year Award for 1997 has been won by 15-year-old Emma Constantine.

Emma has been a founder member and Secretary of her school radio club in West Yorkshire since she was 12. She helps to run Novice training courses for fellow students and friends, and recently facilitated lunchtime Morse code sessions at the school. She is also active in organising contests such as the IOTA (Island on the Air) she is currently planning to help her Novice course candidates. One notable achievement is that she has established educational links with a school radio club in Lithuania, and also a club at Moi University in Kenya.

Her close runner-up is 14-year-old Mark Haynes from Harlow, Essex, who became the youngest radio amateur in his home town at the age of 12, when he gained his novice licence. He helped to set up an Amateur club at his school, and has taught two of his friends Morse code. Mark himself can transmit and receive Morse at around 16 words per minute.

At ETI, we are glad to see young amateurs pitching into fundamental radio skills like Morse code and basic construction instead of concentrating purely on "black box" radio skills.

As winner, Emma received the first prize of £300 from the Radiocommunications Agency's Director of Mobile Services, Roger Louth, at the Radio Society of Great Britain's HF Convention in Windsor. She also received a certificate signed by Margaret Beckett, President of the Board of Trade and Secretary of State for Trade and Industry. Mark received an award of £50 from the Agency, and both winers will be invited to the winner's traditional outing to the Agency's Radio Monitoring Centre at Baldock, Herts, for a conducted tour.

Minister for Industry Barbara Roche congratulated the winners and all who had taken part, and reminded us all that the experience and exercise of their talents in radio will help young people when they enter the job market, particularly in view of the shortage of people with knowledge and experience of electronics.

The Amateur of the Year Award is organised in conjunction with the RSGB to encourage young people to go into amateur radio.

Applicants are expected to demonstrate an interest in good construction and radio operation, using radio to help the community, and encouraging others to be involved in school or science projects involving radio.

For more information about the competition, contact the RSGB at Lamda House, Cranbourne Road, Potters Bar, Herts EN6 3JE. Tel 01707 659015.

RA plans auction of radio spectrum licenses for Universal Mobile Telecomms Service

The Radiocommunications Agency (RA) has placed an advertisement in the Official Journal of the European Communities seeking interest in tendering to provide financial management consulting services. The consultant in question would assist the RA in preparing for a possible auction of spectrum licences for UMTS (universal mobile telecommunications service), the third generation of mobile telecommunications.

This is a preparatory step towards meeting the Government and industry's shared goal of early licensing certainty for UMTS. Another action under way is the formation of a dedicated team with the RA to oversee the UMTS spectrum licensing process.

Any auction in connection with UMTS still remains subject to the successful completion of Parliamentary consideration of the Wireless Telegraphy Bill 1997, including the necessary Royal Assent, and the laying before Parliament of delegated legislation under the subsequent Act, and also subject to the results of the current consultation on the document 'Multimedia Communications on the Move' (31 July 1997). Copies of the document can be obtained by contacting 0171 215 1785, or on the Internet at www.open.gov.uk/radiocom/rahome.htm

Radio and TelecommsCorrespondence School

The Radio and Telecommunications Correspondence School (RTCS) in Teignmouth,Devon, has been conducting tutored and untutored correspondence courses for City and Guilds of London Institute qualifications in Telecommunications and Electronics Engineering course no. 2710, which has been updated to 2720. The course comprises three levels: the Technician Certificate, the Technician Diploma and the Advanced Technician Diploma.

The course can be started at any time of year, and the School recommends it for anyone with a reasonable background of school-level mathematics and science. Students are under the general supervision of Mr. A A Goddard BSc (Eng) MIEE (Member of the Institute of Electrical Engineerings) who is a past member of the examining body of the City and Guilds.

Subjects are taught by a combination of standard approved textbooks, lesson and revision notes, worked examples and examination questions from part City and Guilds programmes.

The RTCS also conducts courses for the RAE (Radio Amateurs' Examination) of the RSGB, and courses covering Microelectronic Systems and Television Principles. Details about courses can be obtained by applying for the relevant prospectus form from RTCS, Handel House, 2 Somerset Place, Teignmouth, Devon TQ14 8EP. Tel 01626 772414.

OVERSEAS READERS

To call UK telephone numbers, replace the initial 0 with your local overseas access code plus the digits 44.

Rugged Electronics

Don't try this at home! But some electronics are designed to be dropped. Mike Bedford explores the main requirements of all-terrain gadgets.

Cellphones, walkie-talkies, digital watches, car immobiliser keyfobs, personal stereos, ghetto blasters, portable TVs, GPS receivers, portable test equipment, digital cameras, camcorders, electronic games, dictation machines, calculators, laptops and hand-held computers - at first sight, these diverse examples of electronics equipment might not have much in common. A dictation machine couldn't be much more different from a Tamagotchi virtual pet. But if you have the sort of mind that finishes the Times crossword in five minutes flat, you've probably already figured out that everything in this list is designed to be taken into the great outdoors.

Portability in electronic equipment is today taken for granted, but it hasn't always been that way. Before the advent of the transistor radio in the late 1950s, electronics was mainly valve-based, heavy, power hungry, and definitely not to be carried around more than necessary. A radio (or should that be a 'wireless'?) was as large as today's desktop PC, and computer engineers were being ridiculed for suggesting that, some day in the future, computers might weigh less than a ton.

Just as technology has changed, so has public perception. Electronic equipment has been thought of as fragile, to be handled with the utmost care. But no longer. Today, people don't expect to mollycoddle it, keep it dry and under no circumstances to drop it. Ironically, the people still treat optical equipment such as cameras or binoculars with respect, and would never dream of dropping a pair of glasses on the floor and stepping on them, but they expect a cellular phone or a laptop computer to soldier on whatever befalls it.

So, how does industry cater for this demand for tough equipment? In this article, we'll look in some detail at what is required of genuinely portable equipment - not only ordinary portables such as a standard cellular phone, which needs a modicum of ruggedness, but ultra-tough kit like laptop PCs targeted at civil engineers and the military. Then, having seen what's needed, we'll take an inside look at how equipment is designed and manufactured to meet the demands placed on it.

What's needed?

Talk of ruggedness in portable equipment and has probably already caused you to jump to certain conclusions. The word
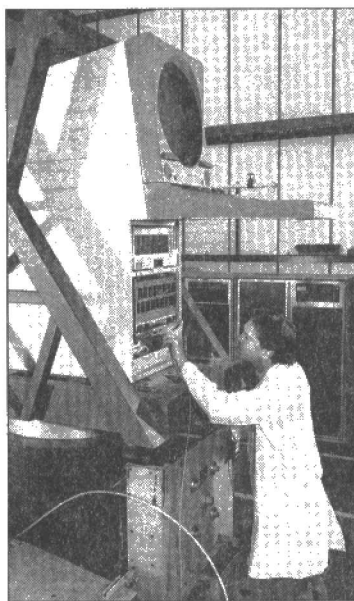
Vibration testing: a sophisticated vibration and shock testing system can take anything from elecronic components to assemblies of up to 2 tonnes in weight. (Seimens Plessey Assessment Services Ltd., Fareham.)

seems to suggest protection against physical threats such as dropping but, whereas this is very important, it's only one example of what "go anywhere" equipment must withstand. In this article, we're using the word rugged in a broader sense. We're talking about immunity to a whole range of environmental conditions. In addition to shock, this includes vibration, water, dust and corrosive liquids, plus extremes of temperature and humidity. @B:Let's start by taking a look at some of these issues and see just what's needed of portable electronic equipment.
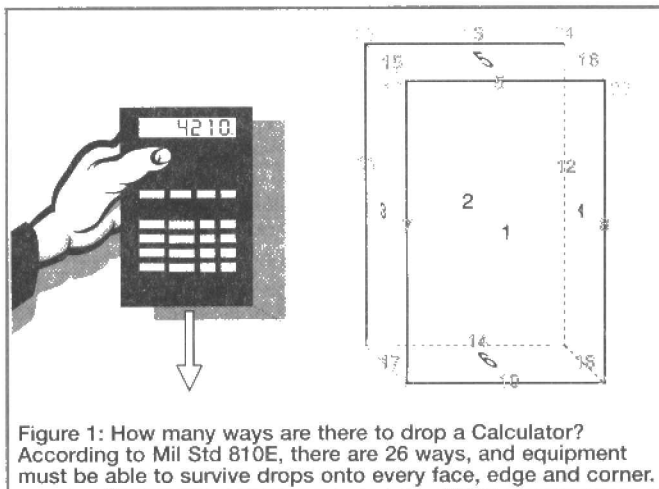

Figure 1: How many ways are there to drop a Calculator? According to Mil Std 810E, there are 26 ways, and equipment must be able to survive drops onto every face, edge and corner.

Shock resistance

Shock resistance sounds a bit formal, so let's put it in everyday terms. To all intents and purposes, immunity to shock means that you can drop the equipment and it'll still keep going. There are undoubtedly other ways to shock a laptop, but dropping it on the floor must be the most common one. So you will frequently see a "drop test" figure quoted, and this may simply specify something like "1m onto a carpeted floor" or "2m onto concrete". But a figure like this is vague and could be designed to pull the wool over the buyers' eyes. For example, is this talking about a drop onto one of the flat faces of the equipment or - potentially more damaging - onto an edge or corner? Does it mean dropping it onto a wooden floor covered with thick pile carpet on overlay, or a concrete floor covered with an industrial carpet? Although quoting a simple drop test figure gives some indication that the kit is tougher than average, many people will need a more rigorously defined specification.

A much more scientific approach to shock testing is specified in the US military standard Mil-Std 810E. This specifies tests relating to just about every form of environmental hazard, but for now we'll concentrate on impact shock.. Manufacturer often quote "Mil-Std 810E", but although this looks impressive, it is meaningless unless you also state which part of the specification the unit has been tested against. Within Mil-Std 810E, method 516.4 relates to shock, and this sub-divides into various procedures. Procedure IV is the drop-test, and requires that a unit must be capable of surviving drops from a height of 1.2m onto a steel plate over concrete. More specifically, the drops must be made onto all 26 faces, edges and corners of the unit under test *(figure 1)*.

The other method of specifying immunity to shock is in terms of acceleration. This is the method defined by the European standard IEC 68-2-27. You will recall that anything in free fall will be subjected to the acceleration due to the Earth's gravity, and that this acceleration is referred to as G. Astronauts, fighter pilots and passengers in fairground rides can be subjected to a much higher acceleration. Unless you are carrying your cellular phone in a Space Shuttle take-off, it is unlikely to be subjected to an acceleration higher than one G, but it can easily be decelerated at a higher rate. Whenever you drop something, it accelerates at one G but, when it hits the ground, it decelerates at a much higher rate depending on the elasticity of the unit and the characteristics of the surface it lands on.

So what is typical? That's anyone's guess. Suffice it to say that the IEC 68-2-27 specification requires protection up to 15G, and it is by no means uncommon to see much higher figures quoted - perhaps up to 100G. Unfortunately, although this is a much more scientific way of specifying shock-resistance than the drop test, it's much less easy for ordinary mortals to understand.

Vibration

Unless you're considering using equipment in a seriously hostile environment, immunity to shock is about accidents, dropping equipment on the ground or dropping a heavy object onto the equipment. Vibration is more of a day to day risk. A car radio, for instance, will be subjected to constant vibration whenever the car engine is running. Anything that is ever carried in a car, plane, ship or train will be vibrated to some extent. Unfortunately for buyers of rugged equipment, vibration specifications are not as easy to understand as drop test figures. There is no standard

that specifies the effect of "100,000 hours in a Ford Mondeo at 7,000 rpm".

Mil-Std 801E specifies immunity to vibration in method 514.4. This states that the unit must survive being subjected to vibrations from 20-1000Hz with an amplitude of $0.04g^2$/Hz and then from 1000-2000Hz at -6dB/octave. The duration of the test is one hour for each axis. Similarly, European specification IEC 68-2-6 specifies the frequency, amplitude, acceleration and duration of the vibrations to be applied.

Unfortunately, these figures are not easy to translate into real world hazards. What is worth considering is why these specifications require the equipment to be subjected to vibration at a broad range of frequencies. The amplitude of vibration of any object increases very significantly when it is excited at its resonant frequency. For example, if the motherboard in a laptop PC has a resonant frequency of 750Hz, there will be comparatively little likelihood of
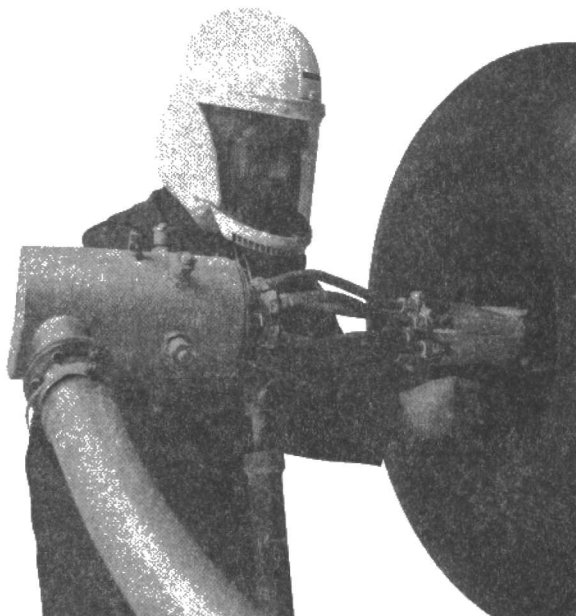
Siemens Plessey's unique complex can meet requirements for all the major specifications for dust penetration in both "swirling" and "driving" conditions. The ability of assess the abrasive effect of airborne dust and sand on surfaces is another important service (below). (Seimens Plessey Assessment Services Ltd., Fareham.)

damage if the unit is vibrated at 600Hz . However, once the magic figure of 750Hz is reached, the PCB will flex violently, with obvious potential for damage. Other parts of the computer may have different resonant frequencies.

Not knowing in advance what these critical frequencies are, the only reliable way of proving the unit's immunity to vibration damage is to carry out a sweep of frequencies. This tends to be carried out using a pressure transducer - basically a loudspeaker without the cone - driven by a variable frequency signal generator under computer control. In addition to subjecting the equipment to vibration, more sophisticated test equipment can monitor the vibrations and identify resonant frequencies.

The Sony CMD-Z1 GSM cellular phone

Waterproofing

Even people who don't know the slightest thing about electronics accept that electricity and water are best kept apart. Modern circuitry can be damaged by even the slightest film of water on the circuit board. I know this from bitter experience of being stranded in the middle of nowhere after getting my car immobiliser keyfob wet. 'Damp' would be a better word - when I opened up the fob there was barely a trace of water on the PCB, but it was two days before it came back to life again and the car could be started. And whereas the contamination was with clean water and the affected equipment did eventually come back to life, dirty water or, worse still, sea water, can be fatal to electronic equipment. Ordinary tapwater in a lime-rich hard-water area doesn't do it a lot of good, either. But making the circuitry itself immune to water is rarely feasible - it would place too many constraints on the designer. Instead, waterproofing electronic equipment normally means keeping water out of the enclosure, and it is this aspect that is normally specified.

But in practice, precise as it sounds, 'waterproof' is a vague term, even where it distinguishes between waterproof and showerproof, as clothing manufacturers do. Although it is normally essential to completely prevent water entering electronics casing, it is harder to do this for a GPS receiver to be used on board a yacht rounding Cape Horn than it is for a laptop which may occasionally be caught in a light shower between car and office. So a standard has been drawn up which specifies exactly how waterproof a piece of equipment is.

The figure is referred to as the 'IP rating', and actually consists of two figures, the first of which relates to another environmental hazard - the ingress of solid objects of various sizes - and the second to the ingress of water. *Table 1* shows how to interpret an IP rating, and a couple of examples should help clarify things.

- IP41 indicates that kit won't be damaged by having wires or larger objects poked into it, or by dripping water.
- IP57 signifies that kit can withstand a dust storm, and can be immersed in a metre of water for short periods.

As an alternative to combining the two figures, you'll sometimes see them separated. So, for example, IP57 could be shown as IP5X for dust-proofing and IPX7 for waterproofing. And occasionally, a unit may not have been tested against either solid objects or water at all - another reason for showing an X in place of a figure in an IP rating. In this case, however, to all intents and purposes, the X should be replaced by a 0 - you can't rely on any level of protection which the equipment has not been tested against.

Table 1

|	First Number (solid objects)	Second Number (water)
0	No special protection	No special protection
1	Protection against damage by objects larger than 50mm (eg hands)	Protection against damage by drops of water (eg condensation)
2	Protection against damage by objects larger than 12mm (eg finger)	Protection against damage by sprays of water up to 15 degrees to vertical
3	Protection against damage by objects larger than 2.5mm (eg tools)	Protection against damage by sprays of water up to 60 degrees to vertical
4	Protection against damage by objects larger than 1mm (eg wires)	Protection against damage by sprays of water from all angles
5	Protection against damage by dust deposits	Protection against damage by low pressure jets of water from all angles
6	Total protection against ingress of dust	Protection against damage by jets of water (eg heavy seas)
7	N/A	Protection against damage by brief submersion to 1m
8	N/A	Protection against damage by continuous submersion at a specified pressure

Temperature Extremes

The final environmental hazard we're going to look at in any detail is extreme temperatures. Issues such as immunity to corrosive chemicals or bomb blasts only apply to very specific categories of equipment, so we'll forget them for now.

There are two quite different issues with regard to temperature. First, there are ranges of absolute temperatures; secondly, there is the matter of thermal shock. For the temperature ranges, two sets of figures are normally quoted, the non-operating temperature range and the operating temperature range. The non-operating range specifies temperatures over which no permanent damage will occur even though, at the extremes of this range, the equipment might cease to operate. The questions a manufacturer might have to address here are whether the case will melt or chemicals will leak from the batteries at elevated temperatures. However, it's unlikely that much information about non-operating temperature ranges will be required of most portable equipment. Much more relevant is the operating temperature range, and here, makers of portable kit do have to take special measures to ensure that it will operate out of doors both on a hot summer's day in Death Valley, Nevada and the middle of winter in Anchorage, Alaska. Not usually both at the same time, however. This brings us to the question of thermal shock.

A piece of equipment may be able to operate from 0degreesC to 30degreesC, but would it be able to survive being cooled down from 30degreesC to 0degreesC in an instant? This may seem to be an extreme requirement (although it's not unreasonable to expect that a black box flight recorder deposited in the Arctic Ocean following the break up of an aircraft will continue to work), but more modest thermal shocks, such as that when a cellular phone is taken from the warmth of an office into the outside air are not uncommon. While the occasional shock of this sort may do no harm, portable equipment has to be capable of surviving many heating and cooling cycles throughout its lifetime. And in case you're wondering, the main reason that thermal shock is a potential problem is because of differential expansion and contraction with temperature. This is a problem not only with rapid changes in temperature. Where the various parts have different levels of thermal inertia, the problem is obviously made worse with rapid temperature changes.

Battery life

Admittedly, battery life has nothing to do with protecting equipment against environmental hazards, but this is not entirely a detour. The main reason that equipment has to be rugged and waterproof and able to withstand temperature extremes is that it will be used outside the home or office, and this usually means that it will not be operating from a mains supply. So the lifetime of the batteries is paramount, and is
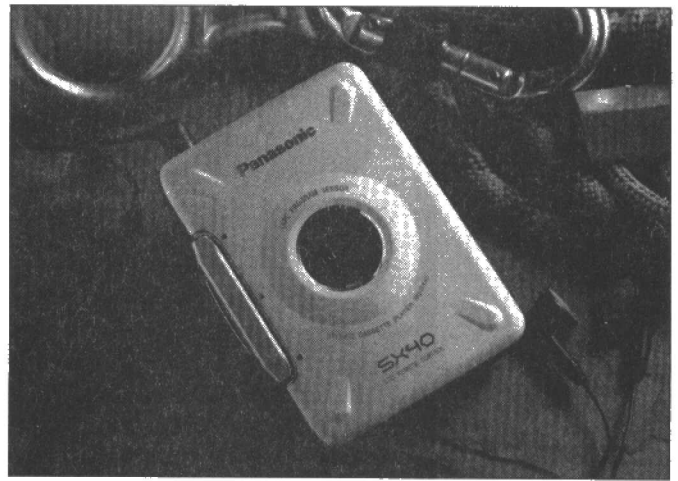
The Panasonic SX-40 personal cassette player - this model is designed to be rugged for outdoor pursuits

often a major selling point with portable electronic equipment. For example, an ordinary business laptop computer may claim a battery life of two to three hours. However, portable PCs that are sold specifically as rugged computers tend to boast a much longer battery life. These are intended for use out and about, all day, every day - the very reason they have to be rugged - and a 10-hour battery lifetime is not uncommon.

Design and manufacture

Since ETI readers want to know what makes things tick, let's now look at how manufacturers design and build equipment to hack it in the great outdoors. Many of the issues we'll cover aren't restricted to large scale manufacturing. So, if you want to build your own rugged equipment, you could pick up some useful design and constructional techniques here too.

Infant mortality

Figure 2 is a graph of the failure rate of a piece of equipment measured in failures per unit time plotted against elapsed time. Although the values will differ from one type of equipment to another, the overall graph is nearly always this characteristic "bathtub" shape.

Let's discuss each of the three marked sections in turn. In the first section we see a high failure rate, dropping off with time. These failures are due mainly to manufacturing faults and are referred to as 'infant mortalities'. Then comes the section where there is a very low level of failures, and we might hope that this happy state of affairs will last for some time. In the graph, the operational life of the product may look depressingly short, but remember that the horizontal axis is not linear - the duration of this middle section has been compressed. Finally, we see the failure rate start to increase again as components begin to wear out. In the case of electronic components, we are not necessarily talking about mechanical wear - it may be an electronic failure - but the same principles apply.

For a piece of equipment which has to survive harsh treatment, there must be two main aims relating to the 'bathtub' curve. First, those units which are destined to fail in the early stages must be identified, and secondly, the time at which wear-out failures start to occur must be pushed as far to the right as possible. The second of these points is heavily tied up with how the product is designed and manufactured. Whereas the number of infant mortalities can be reduced by adopting good quality procedures in both design and manufacturing, the holy grail of zero defects will never by achieved in practice. So the weeding out of rogue units is
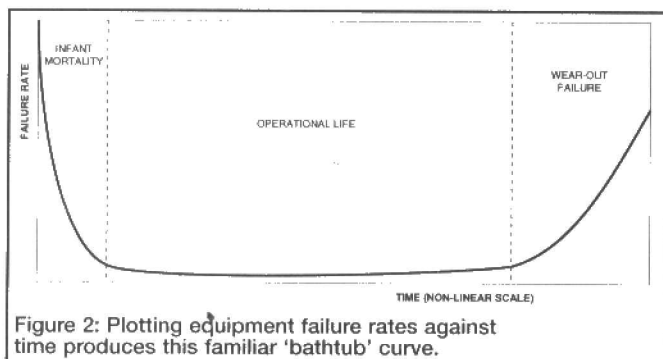

Figure 2: Plotting equipment failure rates against time produces this familiar 'bathtub' curve.

The Panasonic SX50 camcorder

essential. Even if a company's products are sound in every other respect, a smattering of dead-on-arrival units soon dent a company's reputation for producing reliable rugged equipment.

The answer is to soak test units as they come off the production line. But for how long? It is clear that a lot of consumer goods are not soak-tested for very long. Early failures are not at all uncommon. A manufacturer of rugged portable equipment, on the other hand, cannot afford to have many failures in the field, so an extended soak test is essential. How far is it practical to go? It's obvious from the shape of the failure curve that there are diminishing returns after a certain time. Some rogue units will slip through the net, but the dilemma is solved, at least in part, by testing at an elevated temperature and with constant on/off cycling of the power. This sort of abuse will cause infant mortalities to occur earlier, and so allow a significant number of manufacturing failures to be identified in a comparatively short time.

Bringing'em up tough

How do you go about designing something that will take the knocks? There's no single answer, so let's investigate some of the secrets. First of all, the case needs to be tough. The design of plastic boxes may not sound like a high-tech issue, but in fact it is vitally important. However tough you make the circuit boards, if the case of your cellular phone shatters into a thousand pieces, you are not going to place that call. And it is only feasible to design a circuit board which will survive mishap if it's protected by some sort of enclosure. To design a PCB that will soldier on even if the case in hanging in tatters is not economically viable.

To a degree, a rugged case is a simple one - if there's anything which may break off, undoubtedly it will do so. This also applies to switches and such like - rocker switches are better than toggle switches, but better still are switches mounted in a depression on the case so that they are flush with the surface of the case. But although designing a tough case does involve this sort of mechanical detail, it also needs the right material. Although many plastics are relatively impact-resistant, judging by the specifications of rugged PCs, magnesium alloy - often with an elastomer-coating to absorb shocks - seems to be the choice for equipment that has to withstand serious drops. Of course, steel would be tougher, but most people don't want to lug a steel notebook around all day long.

Equipment reliability is often expressed as mean time to failure (MTTF), which is defined as the average time, in hours, before a unit will fail. Strictly speaking, this is not a measure of

reliability since the MTTF is a design feature that won't alter during the life of equipment. However, any unit will become more unreliable as the MTTF is approached. Now for a bit of maths: the MTTF of any piece of equipment depends on the MTTF of the components which make it up, according to the following formula:

$$MTTF_{TOTAL} = 1/\sum_{r=1}^{n} 1/MTTFn$$

Where n components each have an MTTF of *MTTFn*.

Clearly, the total MTTF increases as the MTTF of each component increases, and is also increased with decreasing component count. Here, the word 'component' should be taken in its broadest sense to include solder joints. Joints, as we have all discovered, are often some of the least reliable parts of any electronic equipment. So a couple of clues to designing reliable equipment can be gleaned. First of all, use as few components as possible. In a sense this is redundant information - why would anyone design a circuit with more components than necessary? Economics and common sense would seem to rule this out. However, it certainly points to the need for the highest possible level of integration - something which economic considerations alone may seem to contra-indicate (that is, ICs are still more expensive than discrete components in many cases). But, historically, semiconductor prices tend to start high and drop throughout the life of the component product line. So, being an early user may work out more expensive than using a larger number of older, lower integration ICs, but is, nevertheless, something which a manufacturer of rugged equipment would have to consider seriously.

The Panasonic CF-25 rugged notebook

The second clue to designing-in reliability is equally obvious - use high quality components and employ the very best manufacturing practices to ensure that soldered joints are as reliable as possible. Once again, there will be financial penalties. However, which components will prove to be reliable when subjected to shock and vibration will not always be evident from manufacturers' specification sheets, and equipment manufacturers may have to conduct their own tests to find out which components are the most vibration proof or shock resistant.

To a large degree, shocks and vibrations will affect soldered joints, so it is vitally important in portable equipment to make every effort to reduce their susceptibility to stress. This means keeping PCBs as small as possible, and providing plenty of
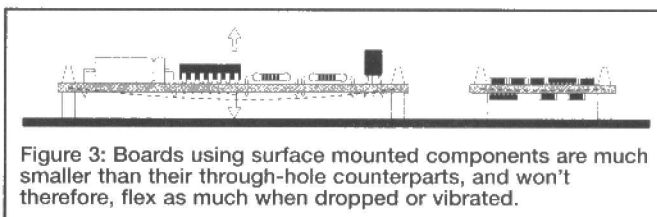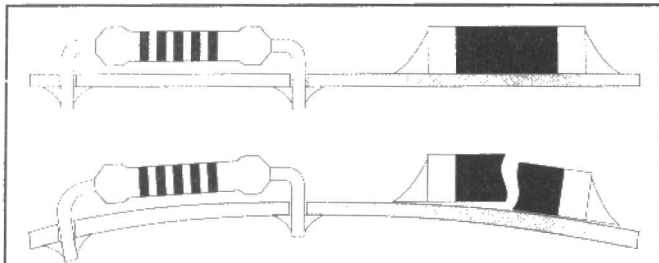
Figure 3: Boards using surface mounted components are much smaller than their through-hole counterparts, and won't therefore, flex as much when dropped or vibrated.

Figure 4: If a surface-mount board does flex, the leadless components may be damaged because, unlike through-hold components, there is no lead to take the strain. But when the pros and cons are evaluated, surface mounting is the clear winner for rugged equipment.

anchor points to the casework to prevent undue flexing of the board. Clearly, a small PCB will not flex as much as a large one, especially if it's supported in the middle as well as round the edges. However, there's another reason to aim for small boards. When we looked at vibration testing, we saw how damage is most likely to occur at the resonant frequencies of the various assemblies in the equipment under test. Since objects are more likely to be vibrated at comparatively low frequencies, it makes sense to aim for a high resonant frequency. A large PCB, especially one with heavy components mounted at its centre, will have a low resonant frequency. So, once again, we can see the advantage of small PCBs.

However, we need to view this recommendation with practical caution. A high degree of integration gets board size down. However, one possible result of restricting yourself to small PCBs is that you could end up with more of them. Multiple small PCBs instead of one large one is seriously bad news, as the interconnects will undoubtedly cause problems - it's nearly always better to have one well supported boards than a pair of interconnected boards.

Hot and cold

As we've already seen, differential expansion is a cause of failure in electronic circuits and goes some way to explaining why non-operating temperature ranges have to be respected. If a resistor on a PCB expands more than the PCB itself as the unit is heated up, stress is placed on the solder joint, and this may lead to failure. Of course, the smaller the components, the less the expansion or contraction with temperature, and this, once again, indicates that to build in reliability, circuit boards should be as small as possible. Whether or not this points to the use of surface mounted components, however, we'll leave to a discussion on the pros and cons of surface-mount and through-hole technology later in this article.

However, size reduction is not the only way of reducing the impact of differential expansion. Different materials have different thermal expansion coefficients, so we might assume that the trick is to pick those components that have a coefficient which is close to that of the PCB. Unfortunately, this is rarely possible - PCB and component materials have their own characteristics. However, you will find that different IC packages have different thermal properties and in particular, that ceramic packages are specified for a wider temperature range than plastic ones. On the down side, military specification ceramic ICs are much more expensive than standard plastic versions. It is also of interest that the improved thermal properties of ceramic packages is tied up with the differential expansion of the elements within the package, rather than that between the package and the PCB. But clearly, the same principles apply.

Designing a piece of equipment to withstand large temperature

ranges does not only involve thermal shock. Looking at operating temperature range, we find that electronic rather than mechanical issues are the key - the operational properties of electronic components also vary with temperature. At one extreme, semiconductors simply stop working at very low temperatures, so components that may travel on an Antarctic expedition or be launched into space may require some source of heat. At the other extreme, semiconductors will also stop working - permanently - if they become too hot, hence the need for heat sinks and/or fans. However, because of battery life considerations, fans are not very suitable for rugged portable equipment. More relevant is the need to design the circuitry to cope with minimum heat dissipation, and careful selection of semiconductors.

It is not only extreme temperatures that affect behaviour. The resistance of resistors and the capacitance of capacitors both change with temperature. A change of a few hundred or a thousand or so parts per million per degree may not sound like much, but it could be significant in a tuned circuit with a fifty-degree operating range. Different types of capacitors have different temperature coefficients, so designing for wide temperature variations means picking those which are least susceptible. Whereas most capacitors have a negative temperature coefficient (that is, the capacitance drops with increasing temperature) some types - polyester, for example - have a positive temperature coefficient, allowing them to be combined with negative coefficient capacitors to give a degree of immunity from temperature change - a very important design technique for temperature-sensitive applications.
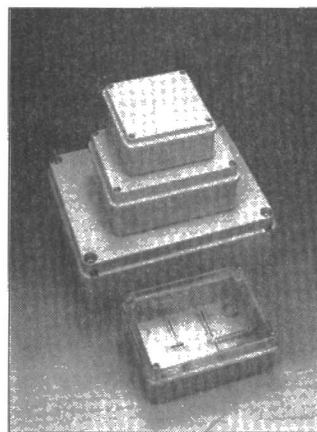
Waterproof boxes are available from about IP54 to IP67. This range of boxes (part numbers YM90X, YM91Y and YM92A) from Maplin is rated to IP55.
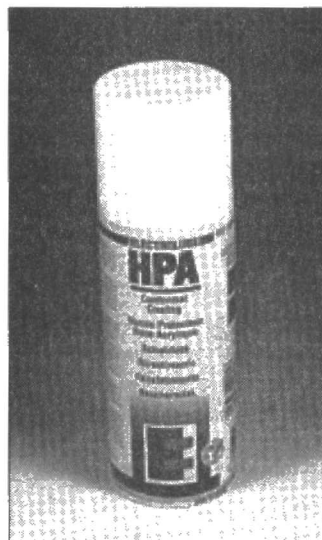
If you want the extra protection, you can spray the PCB with a conformal coating. Pictured is HPA spray (YT50E from Maplin).

SMT or THT?

It is interesting to consider whether surface mounting technology (SMT) or through-hole technology (THT) is better for rugged construction. The answer isn't as simple to answer as you might expect. SMT was designed, first and foremost, as an automated manufacturing system. With a very fine soldering iron and a very steady hand you can build a prototype SMT board by hand, but virtually all SMT manufacturing is automated. The advantages of pick-and-place equipment followed by reflow or wave soldering is that defect rates are much lower than with traditional semi-manual methods of populating circuit boards. (When the equipment is properly adjusted, that is. You don't want to contemplate what

The robust WPI Husky FC-PX5 field computer

happens when the temperatures are set wrongly.) In other words, a more reliable board should come off the production line. On top of this, surface-mount boards are usually quite a bit smaller than an equivalent board using through-hole components and as we've seen, small boards are less prone to damage *(see figure 3)*. And finally, surface-mount components don't have leads to bend - an operation that can introduce a weak spot which may subsequently fail under pressure. So, on the face of it, surface mounting is the favourite for rugged applications. However, there is another side.

Figure 4 shows what can happen to a leadless surface-mounted component and a through-hole component when the board flexes violently. Component leads have a degree of flexion, so the mechanical strain on the solder joint is minimised. This is not the case with the surface-mounted component. The assembly is rigid, nothing is able to give, and a significant amount of stress is placed on the component and its soldered joints. In an extreme case, either the body of the component will crack or the joint will break. The same applies to thermal expansion - leads provide a degree of leeway, but a surface-mounted component will be put under a great deal of stress.

So we have some considerations which favour surface-mounted components and others which favour traditional manufacturing. Which technique should you use in designing for a harsh environment? I asked Rod Coleman of WPI-Husky Computers Ltd., manufacturers of ultra-rugged PCs and hand-held computers, who felt that the advantages of surface mounting far outweighed the disadvantages. He pointed out that many sm components do have leads to take the strain, and chips with gullwing or J-leads would be chosen in preference to leadless chip carriers. The leadless passive sm components are usually not large enough to be a problem. Although every effort would be made to source a leaded part, in any case where a large leadless component is used - a capacitor, for example - Husky minimises the effect of board flexing by placing the component near the edge of the board. He also emphasised the paramount importance of adequate board support to prevent flexing.

Redundancy

When you've spent millions of dollars placing a piece of electronic equipment on the surface of Mars, you're going to be a little upset if it fails on arrival. Take the Sojourner robotic explorer deposited on the red planet by the Pathfinder spacecraft earlier this year. Now, we can reasonably expect that the circuitry inside that tiny robot was designed and built to the highest standards of reliability, using all the tricks of the trade we've discussed so far. However, NASA engineers used an additional technique for one of the critical circuits. In order to provide a soft landing, the Pathfinder spacecraft was fitted with airbags for deployment immediately before touch-down. Clearly, correct operation of the airbags was paramount - if they didn't inflate at the right time, NASA engineers would haveacquired a very expensive pile of scrap iron. So, the circuitry responsible for inflating the airbags was duplicated. Obviously, the chances of both circuits failing at the same time is much less than the probability of one of them failing.

This technique is usually called 'redundancy', and it was actually used less in Pathfinder than in some of the earlier planetary probes. This was due partly to improving reliability and partly to financial constraints - more circuitry would need a larger spacecraft to carry it, and Pathfinder is the first of a new breed of low-cost missions. But in other areas, especially where lives would be at risk in the event of failure, redundant circuitry is an important technique. This is rarely justifiable in portable consumer equipment, and tends to be used only where the cost of failure is far higher than the cost of the equipment itself.

Sometimes, it's possible to introduce redundancy without adding complexity. For example, rather than using a single pole on/off switch, additional reliability could be provided by using a double pole on/off switch and wiring the two poles in parallel. In passing, I should point out that this is only an illustration. It would only increase reliability if the expected failure mode is for the contacts go open circuit - if the contacts were to weld together, this would be no help at all. Usually, redundancy can only be provided at the cost of additional circuitry. Some of the earlier NASA deep space probes had three computer systems. Of course, you can't just parallel the outputs of these three systems. You need a majority voting system: some additional circuitry to make a final decision based on the output of all three systems, basically ignoring one of the computers if it disagrees with the other two. But you easily can't duplicate the majority voting system itself, so this is still a single point of failure. The implication is that the whole system must be as simple as possible and that the utmost care must be taken in its design and manufacture.

Wet and dry

Last on our list of environmental hazards and how to avoid them is water - perhaps the greatest enemy of all to portable equipment. Designing to withstand rain storms or being dunked in water is largely a matter of arranging a waterproof housing. Designing the actual electronics to operate while saturated a challenge not normally attempted. For waterproof enclosures, suffice it to say that they normally have tight-fitting lids fitted with a waterproof gasket. Both plastic and metal boxes can be designed this way, and if you look through a good electronics catalogue, you'll see boxes with specifications ranging from about IP54 to IP68.

However, there's a snag - it's very unusual for equipment to be devoid of switches, indicators, microphones and such like, and to fit them you need to cut a hole in your waterproof enclosure. Apart from holes compromising the

waterproofing of the box, most of these components are not themselves waterproof. However, it probably comes as no surprise that you can buy waterproof switches, push-buttons, indicators and even microphones and speakers that are both water tolerant and provide a waterproof seal to the box. Cost is a snag. Looking through the Farnell catalogue, the cheapest IP67 push-button I could find was priced at £4.27 compared to about £1.50 for the "leaky" types. As a more cost-effective solution, some types of switch can be fitted with a waterproof rubber sealing "boot" which totally encloses the toggle or push-button.

As an additional measure, to provide some protection should a small amount of water penetrate the enclosure, manufacturers often apply a conformal coating to the completed circuit board. This is sprayed over the PCB, coating the surface of the board and the components, providing additional protection against moisture and corrosion. It is available in small aerosol cans for use in prototyping or one-off production.

Case Study - The Husky FC-PX5

This article has mostly looked at what the customer needs in rugged portable equipment and the basic principles involved in making equipment rugged and waterproof. Let's now come down to earth by looking at a piece of real-world rugged electronic equipment, specifically a rugged portable PC. Mainstream laptops are becoming ever more rugged as is evidenced by Panasonic's CF-25 which can survive modest drops and rain showers. However, there are also specialist manufacturers of ultra-rugged portables intended for niche markets such as the police, fire services, the military, civil engineers and shop-floor use. One such product is the FC-PX5 from WPI-Husky Computers Ltd. This is interesting to look at - its specification and design illustrate many of the points we've described. However, as a computer, a number of other issues have had to be addressed and the FC-PX5 is very different from run-of-the-mill laptops in certain respects.

The environmental specification of the FC-PX5 is very impressive indeed. It can be dropped 2m onto concrete and, at IP67, it can be immersed in a metre of water for short periods. Given these facts and having read the rest of this article, you won't be surprised to

hear that it's housed in a totally sealed magnesium alloy case and the potential weak spot in any laptop - the hinge - has been eliminated by virtue of the fact it doesn't fold up. And while not actually a measure of ruggedness, it can be operated all day long on a single battery charge - important for equipment intended for extended use out of the office.

The basic computing specification may seem less impressive to users of business laptops. At 133MHz, the processor is slower than some, but it's the hard disk specification which will surely be an eye-opener at just 20Mbytes on the basic model. With most entry-level PCs now boasting at least 2 gigabytes - one hundred times larger - it's pertinent to ask "why is the disk so small?".

First of all, let's provide a justification. These PCs are not used for running standard office applications - the ones which can easily take up tens of megabytes each. Instead, they will probably be used with custom applications that are much more frugal in disk space. Secondly, user data won't accumulate on the disk - typically, data will be downloaded to a desktop PC at the end of each day's data gathering. So for most of its intended applications, this tiny disk will be adequate. It's still worth asking why the disk is so small, considering the low prices of large disks. The answer is - that the FC-PX5 doesn't actually have a disk at all. To meet the requirement of surviving a 2m drop, the potentially fragile hard disk is replaced by solid state memory which emulates a disk. Of course, this also helps to meet the need of low power-consumption, but it means that the disk must be small - flash memory is much more expensive than magnetic storage. The other departure from normal practice is that the FC-PX5 has no floppy disk drive or CD-Rom drive. Either of these would make it virtually impossible to achieve IP67-level waterproofing. Data is transferred in and out of the computer via its communication ports.

This computer is interesting as it shows how, in some areas, an impressive environmental specification in some areas can only be achieved by compromising in other areas. It also shows, however, how this is no problem if you consider what a customer actually needs, rather than engaging in the "specmanship" wars.

This month's cover shows a WPI Husky FC-486 field computer facing one of "a host of demanding situations which have not been addressed by any other computer manufacturer."
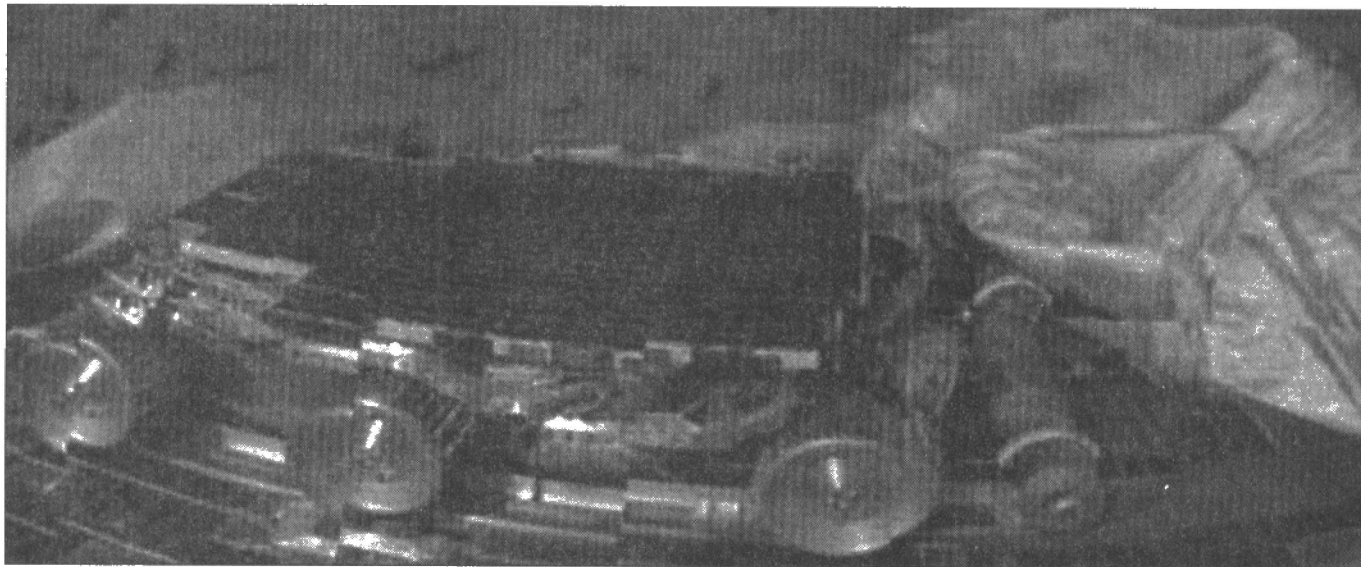
The recent Sojourner Martian robot in action. The Pathfinder spacecraft which took the rover to the red planet used redundant circuitry to deploy its air bags.

You can "shoot" your hifi or other infra-red remote control signals round corners with this uncomplicated extender unit by Robert Penfold

nfra-red remote control systems originally became popular as "zappers" for television sets, but these days just about every electronic gadget around the house seems to have its own remote control handset. At the last count I had six of them, giving remote control of a video recorder, a 35mm SLR camera, a mini hi-fi system, a VCR, and two television sets. Infra-red remote controllers can also be used for such things as controlling lights, servo systems to operate curtains, and so on, and many other everyday applications. A versatile controller for general on/off switching applications will be featured in a future issue of ETI.

Just around the corner

Although infra-red remote control systems are suitable for many applications, their short operating range and line of sight operation can be a definite drawback. The pulses of infra-red "light" are at frequencies just below the visible red part of the light spectrum, and they cannot pass through anything opaque. The maximum operating range varies from one system to another, but is not usually more than about 6 metres, and in some cases is only about half this. Infra-red is not the medium to use where long range or operation through several walls is required, but the scope of this method of control would be greater if slightly longer range could be obtained, together with the ability to operate around corners.

This simple gadget is an infra-red repeater that receives the pulses from the transmitter and retransmits them towards the receiver. One way of using the unit is as a range extender. For example, with something like a remote controlled still or video camera, you are unlikely to obtain satisfactory results at a range of 10 metres. In fact, the camera would probably fail to respond to the transmitter at all. Using the extender unit half way between the transmitter and the camera would give a range of five metres from the transmitter to the extender, and the same distance from the extender to the camera. This should just about give satisfactory operation with most remote control systems.

The second method of operation is to position the repeater in the corner of an 'L' shaped room, or in a similar situation where the infra-red signal must negotiate a corner. With the receiver situated in one section of the room and the repeater aimed at it, the receiver can be operated from the other section of the room by aiming the transmitter at the repeater. This round-the-corner mode of operation is not likely to be of much practical use with something like a television set, where there is no point in controlling it unless you can see it! On the other
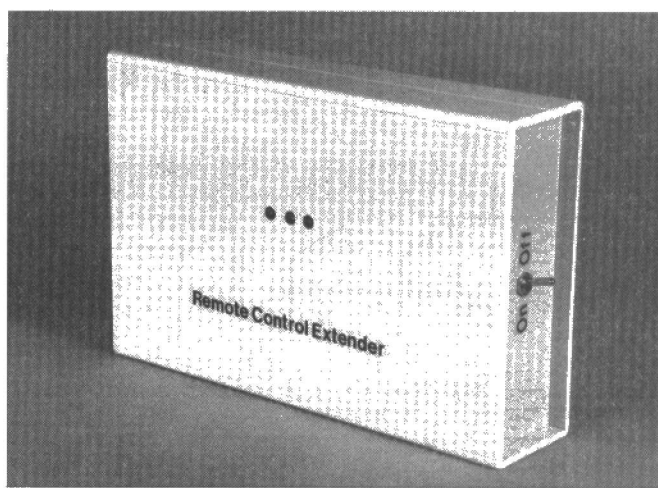
hand, it could be useful with something like a remote controlled hi-fi system, radio, curtains, and so on.

Although it might seem reasonable to expect the repeater to double the maximum operating range of the system, the actual increase in range is likely to be slightly less than this. When operating at extreme range the signal tends to be degraded somewhat at the output of the receiver. When operating with both the receiver and the repeater at extreme range this degradation occurs twice, probably resulting in an output signal of inadequate quality. The typical increase in range is therefore about 80 percent rather than 100 percent, but this is obviously to some extent dependent on the characteristics of the remote control system.

The long and the short

For the repeater to function properly it must not distort the signal in a fashion that would prevent it from being decoded properly at the receiver. The transmitted signal is usually a binary value sent in serial form. In a conventional serial system, such as the familiar RS232C type fitted to many computers, the binary 1s and 0s are represented by a high or low voltage. The duration of each bit is the same regardless of whether it is set at 1 or 0. This system is fine if dc coupling is used, but does not work well if the system must use ac coupling. In order to obtain good sensitivity it is essential for an infra-red remote control receiver to use a very high level of voltage gain. To avoid problems with drift it then becomes necessary to use ac coupling. The asymmetric nature of a conventional serial signal this tends to lead to "smearing" of the waveform, which renders it impossible to decode accurately.
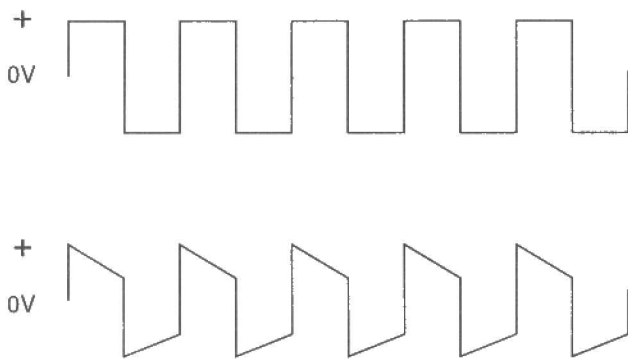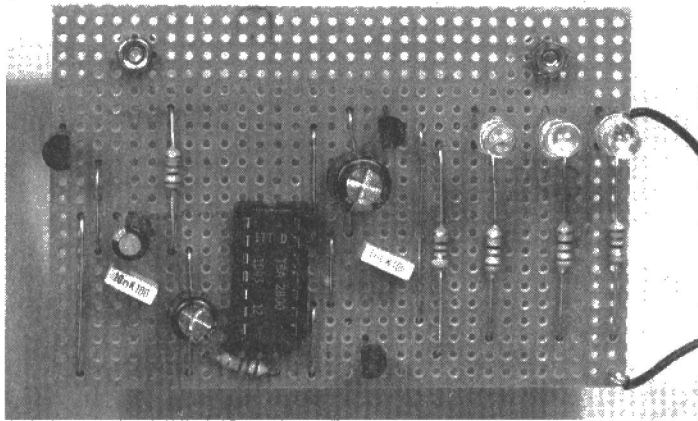
Figure 1: a pulse signal (top) becomes distorted (bottom) by an inadequate low frequency response

The special encoder and decoder chips for use in infra-red remote control systems invariably adopt a different approach, with the 1s being sent as long pulses, and the 0s being sent as short pulses (or vice versa). Due to the good symmetry of the signal there is no major problem with "smearing", and the use of ac coupling is not likely to give any problems. Even with a certain amount of "smearing", the long pulses can still be sorted out from the short pulses with a high degree of reliability, and it is not even necessary to use any complex circuitry in the decoder. Although ac coupling is acceptable, it is essential that any system handling the signal has an adequate low frequency response. Figure 1 shows a pulse signal (top), and the affect of a slightly inadequate low frequency response on that signal. The waveform is clearly distorted, and is effectively shortened somewhat. This shortening is unacceptable as it reduces the difference between the short and long pulses, making correct decoding very difficult.

In practical remote control systems, the longer pulses are actually quite short in absolute terms, and are usually no more than a millisecond or so in duration. This enables the system to incorporate highpass filtering which gives low sensitivity at 100Hz, where there will often be "hum" from mains powered tungsten lighting, while still giving an acceptable output waveform.

System operation

The block diagram of figure 2 helps to explain the general way in which the remote control extender functions. Most of the active circuitry is contained within a special preamplifier integrated circuit, the TBA2800, and this chip is represented by the area within the broken line. The infra-red sensor is a special photodiode which incorporates a "daylight" filter that greatly reduces its sensitivity to visible light, but maintains good sensitivity to infra-red signals. The diode is used in the reverse biased mode, and this relies on the fact that the leakage current of a photodiode increases roughly in proportion to the applied light level. Ra represents the internal load resistor for the photodiode, but in reality the load is actually a semiconductor type, and the photodiode is direct coupled to the input of the input amplifier (A1).

The output from this amplifier is coupled by discrete capacitor Ca to the input of the second amplifier (A2). TRa and Rb act as a simple emitter follower buffer stage at the output of A2, and from here the signal is coupled by way of another discrete capacitor (Cb) to the input of the third amplifier stage, A3. The two coupling capacitors have quite low values so that they provide the required highpass filtering. The combined voltage gain of the three amplifiers is quite high at around 80dB or so, giving what will normally be a clipped output signal. The biasing of the third amplifier is arranged to provide an output that is normally high, and produces low pulses when an input signal is present. An inverter provides the alternative of a normally low output that provides high output pulses, and it is the inverted output that is used in this circuit.

Although the output pulses from the preamplifier chip have an amplitude of a few volts peak-to-peak, the available drive
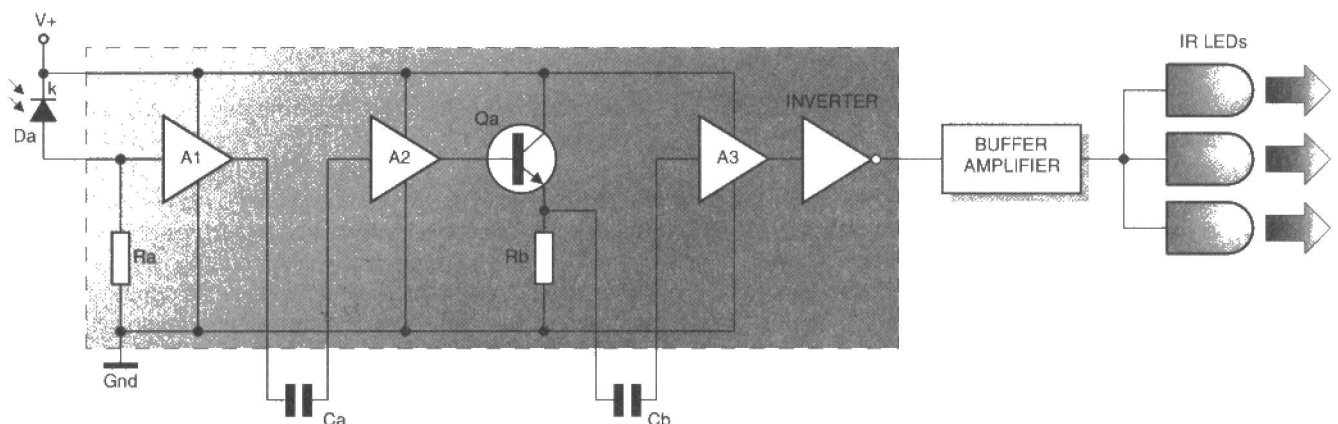

Figure 2: the remote control extender block diagram. The area within the broken line represents the preamplifier
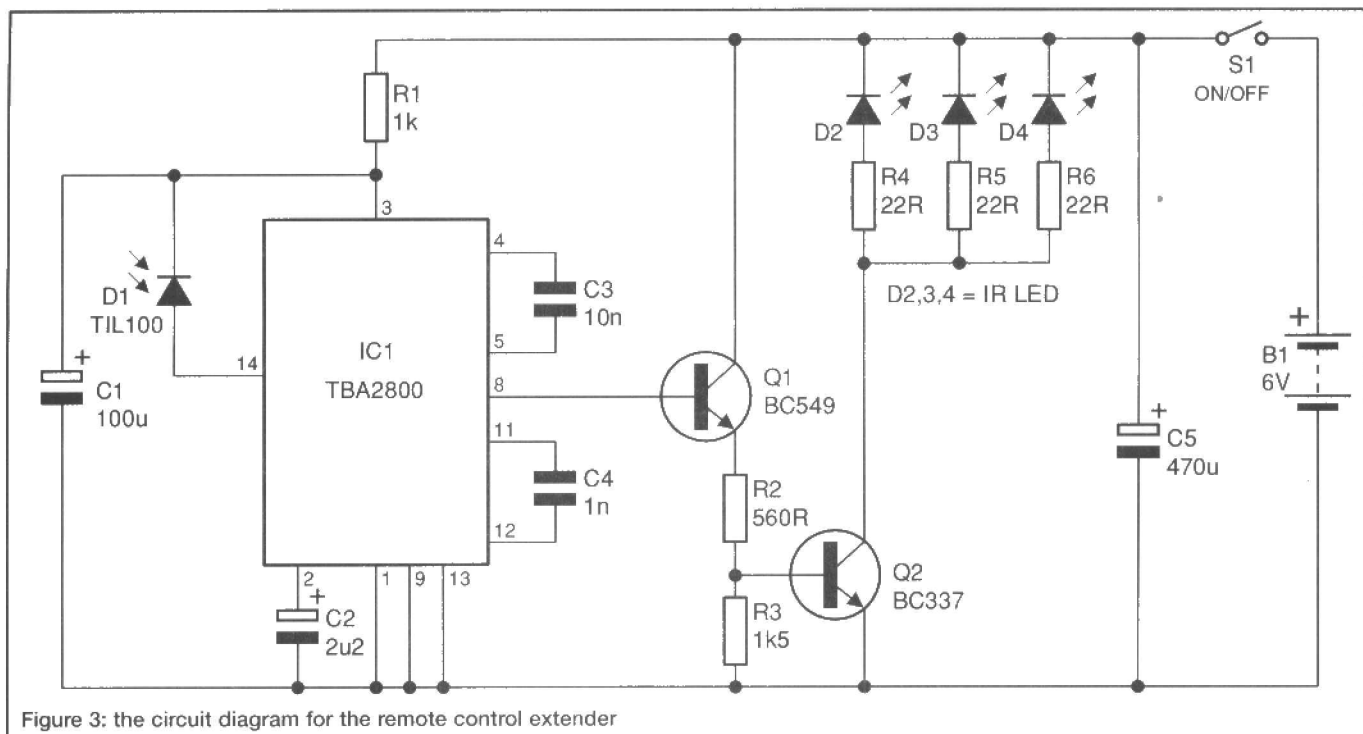
Figure 3: the circuit diagram for the remote control extender

current is strictly limited. A buffer amplifier is therefore used to boost the output current to a level that can drive three infra-red LEDs properly.

The circuit

The circuit diagram for the remote control extender appears in figure 3. IC1 is the TBA2800 preamplifier chip, and it requires few discrete components. R1 and C1 are the supply decoupling network for IC1, and R1 also drops the six volt battery supply down to the five volts required by IC1. D1 is the infra-red detector diode, and it simply connects between the positive supply pin and input terminal of IC1. C2 is a decoupling capacitor for the input amplifier. The inter-stage couplings are provided by C3 and C4. The specified values give good attenuation at 100Hz, but provide an adequate low frequency response for the remote control units tried with the prototype. If necessary, higher values could be used to improve the low frequency response, but this would make the unit more vulnerable to interference from mains lighting.

Q1 is used as an emitter follower buffer stage which ensures that the output pulses from IC1 drive switching transistor Q2 with a suitably high base current. TR2 drives three infra-red LEDs (D2 to D4) via individual current limiting resistors (R4 to R6). The current through each LED is about 100 milliamps or so, but the average current consumption is much lower than this. Despite the high drive current, the LEDs are therefore in no danger of being "zapped."

The standby current
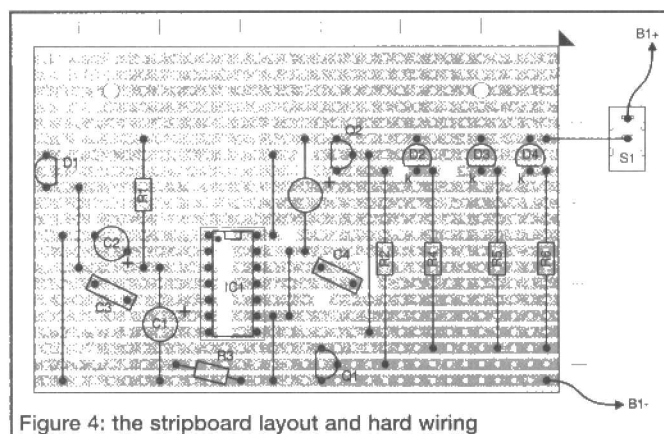
Figure 4: the stripboard layout and hard wiring
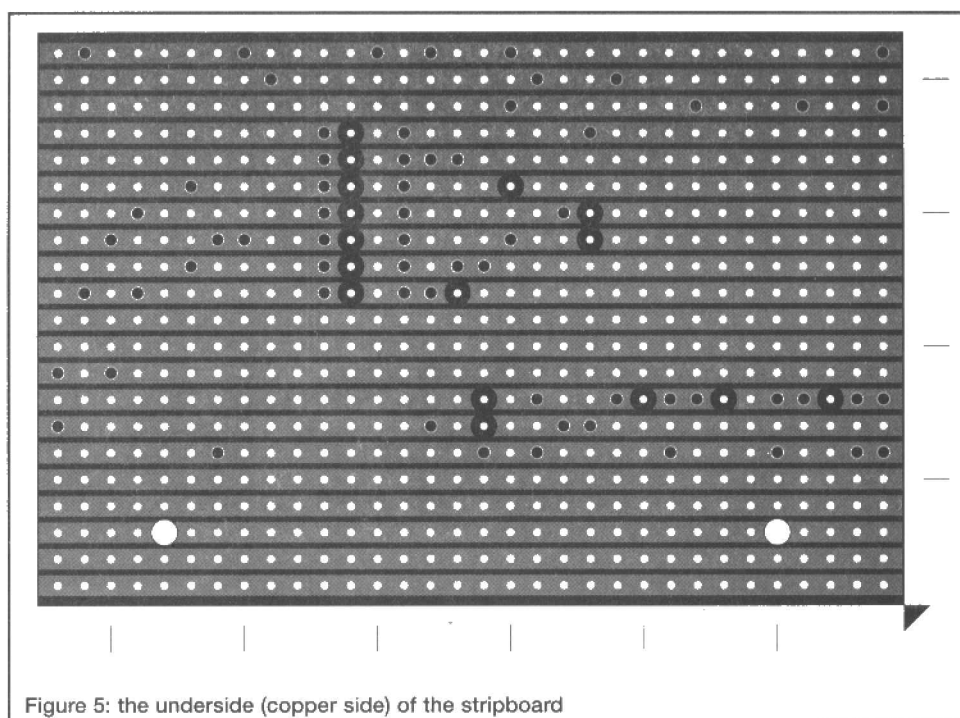
Figure 5: the underside (copper side) of the stripboard

consumption of the unit is the one milliamp or thereabouts consumed by IC1. This low quiescent current consumption enables the unit to be powered from a six volt battery, even though it will probably be left running for long periods. Even with heavy use of the remote control unit, each set of batteries should give about three months of continuous operation. The unit can be powered from a six volt regulated battery eliminator if preferred, but it should have a current rating of 200 milliamps or more. Do not power the unit from an unregulated battery eliminator.

Construction

Figure 4 shows the component layout for the stripboard panel, together with details of the hard wiring. The underside view of the board appears in figure 5. The board measures 32 holes by 21 copper strips, and construction follows along the normal lines. Cut the board to size, drill the two mounting holes, and then make the breaks in the copper strips. The components and link-wires are then added, but IC1 should be fitted in a holder and not soldered directly to the board.

D1 is specified as a TIL100 in the components list, but any similar photodiode is suitable (that is, a large type having a built-in "daylight" filter and no lens). A Maplin "Infra-Red Photodiode" (YH71N) is used on the prototype, and figure 4 is correct for this component. If you use an alternative make quite sure that it is connected the right way round. The unit will not work at all unless D1 has the correct polarity. The three LEDs must also be fitted the right way round if the unit is to work properly. Some five millimetre infra-red LEDs seem to lack the "flat" on the cathode (+) side of the body, but the cathode lead should be slightly shorter than the anode lead. Some suppliers sell five millimetre infra-red LEDs as such, rather than under a particular type number. Any components of this general type that are intended for use in remote control systems should work well in this unit. A type which has a narrow beam will give noticeably better results than a wide angle type.

To some extent the mechanical side of construction must be varied to suit the way in which the unit will be used. The prototype was designed for round the corner operation, and it has a window at one end of the case to permit the infra-red signal to reach D1. Three holes strategically positioned in the front panel accommodate D2 to D4, which are aimed at right angles relative to D1. If the unit must operate as a range extender, probably the best way of handling things would be to have the three LEDs mounted in holders at the end of the case opposite the one having D1's window. The LEDs would then have to be hard wired to the circuit board.

Testing, testing

If you have access to a multimeter it is advisable to check that the finished unit has the correct standby current consumption of about one milliamp. Aiming the remote control transmitter at D1 and pressing one of the control buttons should result in a higher and probably unstable reading. Although the total LED current is quite high, the pulsed and intermittent nature of the output signal means that the average current consumption is never likely to be much more than about 30 milliamps. Note that there will probably be a strong but brief current flow at switch-on while the capacitors take up their normal operating charges. Assuming all is well, the unit is ready for testing.

Bear in mind that the output from the LEDs must be aimed towards the receiver with reasonable accuracy if the unit is to function well, especially if you are using narrow beam LEDs. Obviously it has not possible to check the unit with every infra-red remote control system in existence, but when tried with

Remote Control Extender

half a dozen system it worked well in each case. Provided it is used with a system that utilises one of the standard remote control encoder/decoder chip sets there should be no problems.

A sensitive and selective design for the serious Medium Wave listener and DX enthusiast, by Raymond Haigh

Tune into the world of Medium Wave radio

f you enjoy listening to news, views, sport or popular music; if you respond to the challenge of receiving distant or 'difficult' stations, or if you are just a band browser, you will find something to interest you on the medium wave band.

Extending from 520 to 1620 kHz (530 to 1700 kHz in North America), there are more than 100 different BBC and commercial stations operating on medium wave in the UK. Most have outputs ranging from 100W to 2 kilowatts, but the BBC do run a few more powerful transmitters. These include one at Orford Ness, Suffolk, for the World Service (500kW), at Droitwich and Brookmans Park for Radio 5 Live (both 150kW), Westerglen and Burghead for Radio Scotland, Washford for Radio Wales, and at Lisnagarvey for Radio Ulster (all 100kW). Of the commercial operators, Talk Radio UK and Virgin Radio have a number of stations working at 100kW, and Virgin puts out a hefty 250kW from its aerials on Moorside Edge in West Yorkshire.

The more powerful transmissions can be received over considerable distances, and stations with much lower outputs can usually be heard clearly, well beyond the intended service area, if a sensitive and selective receiver is used.

News and comment broadcast by local stations often has a strong regional or specialist flavour, and eavesdropping on them can be interesting. Restricted Service Licenses are held by several football clubs, and also by some organisers of sports events and race meetings, and they transmit commentaries on match and event days. Power output is restricted to a meagre 1W, and reception beyond a few kilometres from the transmitter is something of a challenge. They are, however, regularly picked up by enthusiasts at distances of 100 km and more. Indeed, Radio Rovers from Blackburn in Lancashire has been heard as far away as Skogsvagen in Sweden.

UK national, regional and local stations dominate the band by day, when propagation is almost exclusively by means of the ground wave. After dark, and around sunrise and sunset, the condition of the ionosphere changes, and sky-wave propagation makes European stations much more evident. Some powerful Middle Eastern and North African transmitters can also be heard then. Austria, Belgium, Finland, Holland, Norway, Poland, Russia, Sweden and Vatican City all make broadcasts in English as part of their programme scheduling, so you do not have to be a linguist to enjoy their different
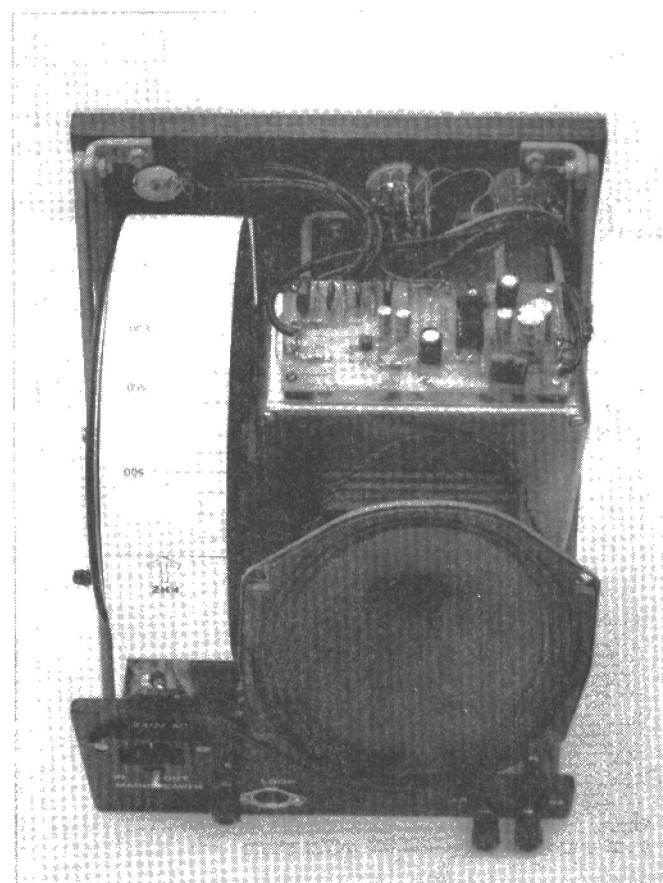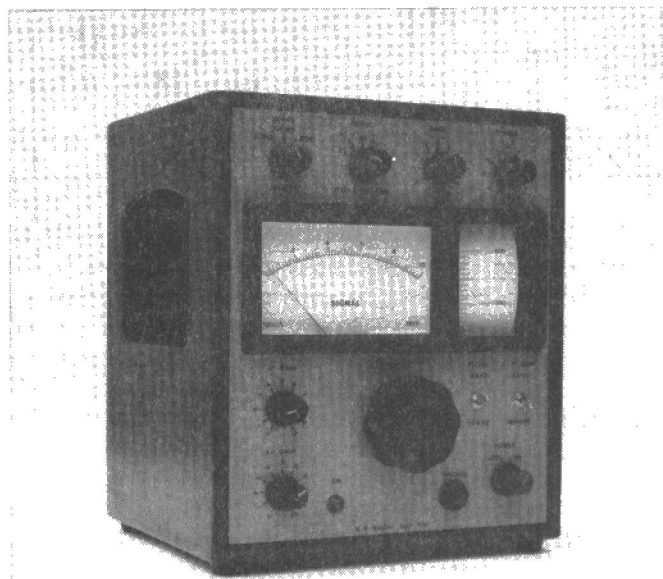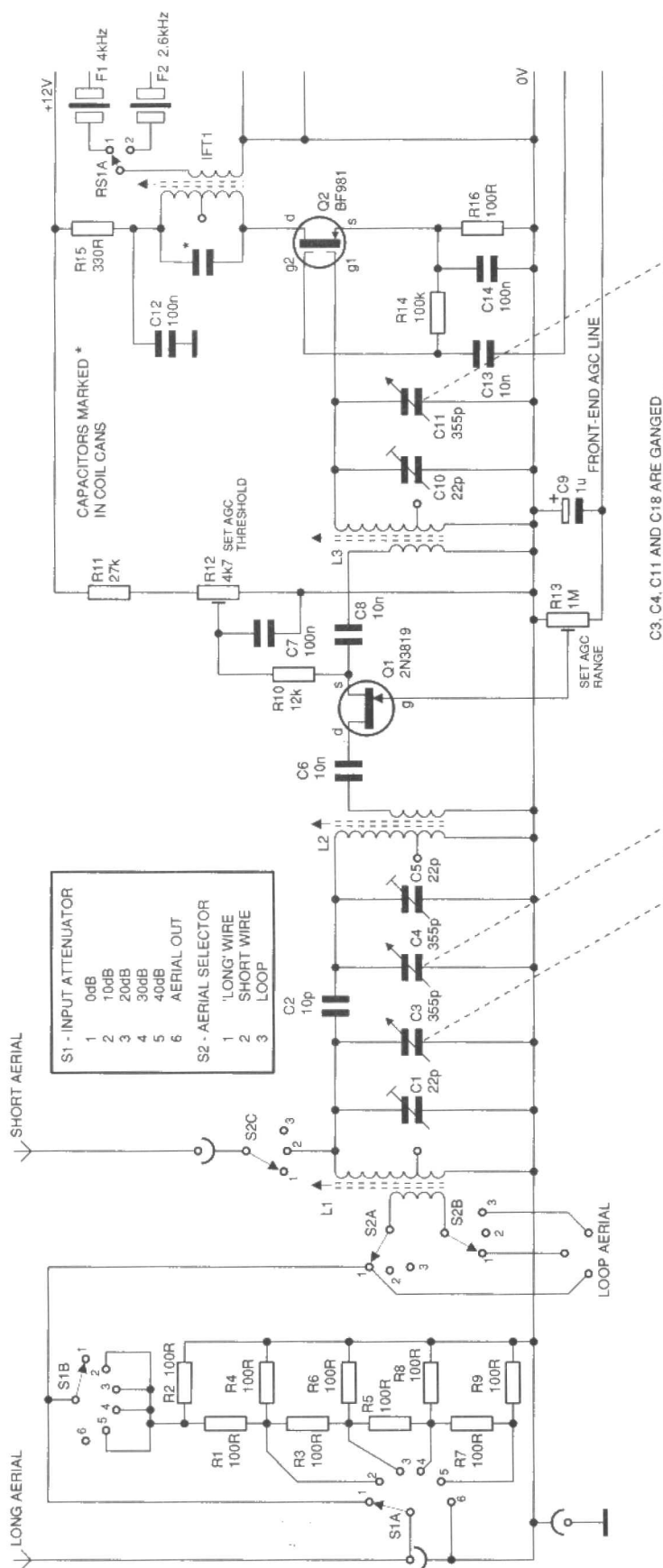
Figure 1a: the aerial selector and input attenuator stages, the RF tuning stage, front-end AGC stage and the mixer stage

perspectives on world events.

The 120 or so channels within the medium wave band are allocated by international agreement. More than one station can be transmitting on a particular frequency, with regard to location and power output to minimise interference. Receiving some of these calls for a directional aerial, and a suitable design is the subject of a future article.

Although broadcasts from as far away as Chile and the Philippines have been received in the UK, medium wave DX is often seen as the reception of Canadian and American stations, which mostly operate at powers below 50kW. Success is very dependant on propagation conditions while the two continents are linked by a path of darkness, but stations to listen for are CJYQ in St James, Newfoundland, on 930kHz; and WINS and WFAN in New York, on 1010 and 1050 kHz respectively.

Band congestion does not make transatlantic reception easier, but differences in channel spacing (9kHz in Europe and 10kHz in the USA) result in frequencies where there is a separation of 4 or 5kHz between transmissions. These 'window' channels include 590, 680, 850, 940, 950, 1130 and 1220kHz, frequencies which all carry Canadian or American stations. Patient listening after midnight can be rewarded by the sound of a broadcast from the New World.

What the receiver requires

Having weak and strong signals on adjacent channels requires a receiver with good dynamic range and linearity if cross modulation problems are to be avoided. Sufficient, but not excessive, gain coupled with good selectivity is important. The view is sometimes expressed that noise generated within receivers at medium and moderately high frequencies is unimportant because man-made and natural interference (band noise) invariably exceeds it. This type of noise, or hiss, is very clear between stations when the AGC system turns up amplification under no-signal conditions, and can be very tiresome when an excessively sensitive receiver is tuned across the band. There is no point having a receiver that makes the situation worse, and the necessary level of amplification should be achieved without adding needlessly to the noise. Audio must be good enough to serve the many stations that can be received free from fading and interference. Spurious responses, in the form of heterodynes (whistles) and images (the same transmission received at two points on the dial, usually separated by twice the IF) should be of a low order.

Some enthusiasts use quality transistor portables to surf the band. An external loop can be inductively coupled, and greatly improves performance. It is not possible, however, to connect a long-wire aerial to receivers of this kind without causing serious overload problems. Unless the portable is of exceptional quality, its selectivity will leave much to be desired.
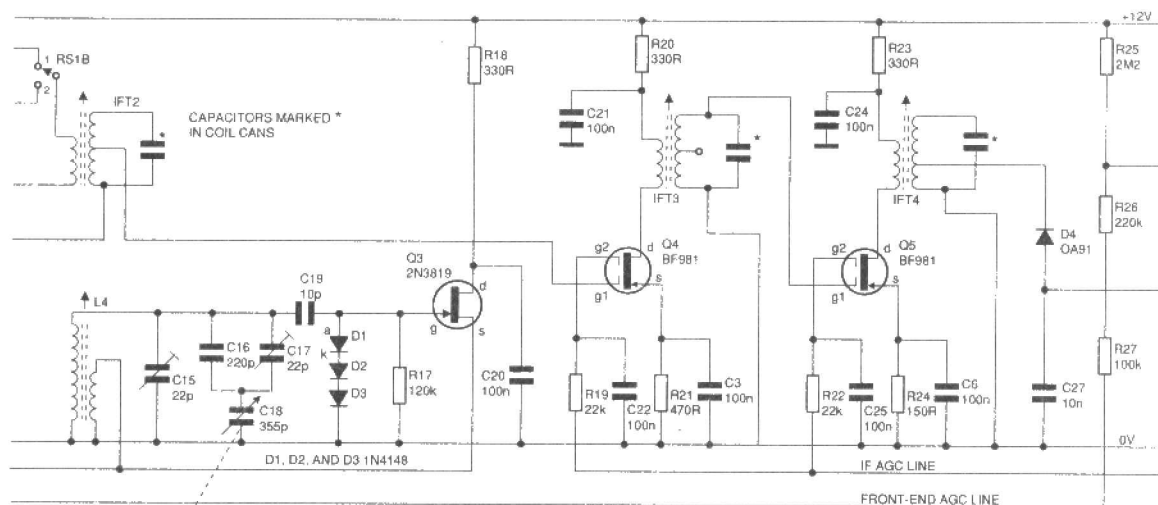
Figure 1b: the local oscillator, IF filter, IF amplifier and detector stages, moving into the signal strength meter and AGC amp stages

Serious listeners often use communications receivers, but

Serious listeners often use communications receivers, but this is an expensive solution if your interests lie mainly in the medium wave band. Their multiple conversion systems (needed to avoid images on the HF bands), circuitry to resolve Morse and single-side-band transmissions, and complex measures to eliminate tuning drift, are not necessary for reception on medium waves. Also, the fixed-tuned filters used ahead of the first mixer in most modern communications receivers do not perform as well as variably tuned RF circuits, especially at medium frequencies, and a simpler, single-conversion receiver with variable front-end tuning is often less noisy for a given level of signal amplification.

The receiver

The receiver described here has been specially designed for the medium wave. Restricting coverage to the band eliminates wave-change switching, and it is comparatively easy to incorporate more than one stage of RF tuning ahead of the mixer. Selectivity can be altered to suit different reception conditions, and signal frequency amplification can be set manually to achieve the best possible signal-to-noise ratio. The AGC system acts ahead of the mixer, and this helps to prevent receiver overload. Output is held reasonably constant over wide variations in signal input, and the audio quality is very satisfactory.

I have adopted a modular form of construction to enable constructors to use alternative audio amplifiers or power supplies if they wish. Suggestions are made for simplifying the circuit to help those who would prefer to build a less complicated receiver, at least in the first instance.

The circuit

The full circuit of the receiver is given in figures 1a, 1b, 1c/d and 1e. FETS (field effect transistors) are used for all the RF amplifying and processing stages. Their valve-like attributes make these devices a good choice for high performance receivers designed around discrete components.

Aerials and input

S2 enables different aerials to be switched into circuit so that rapid performance comparisons can be made (figure 1a).

'Long wire' aerials (in excess of, say, 10 metres), can be connected via the switched attenuator formed by S1 and R1-R9 to the low impedance coupling winding on L1. Even traditional valve circuitry can be overloaded by strong signals, and as the growth of commercial radio brings fairly powerful transmitters close to many listeners, a means of attenuating the high signal voltages that can be delivered by 'long wires' is essential. Short wire or whip aerials, which present a high impedance at medium frequencies, are connected directly to the 'hot' end of L1 (the tuned circuit has a high impedance at resonance).

A dedicated medium wave receiver would be incomplete without some means of connecting a loop aerial via screened cable. Accordingly, the coupling winding on L1 can be isolated from the 0V rail to avoid disturbing loop balance, and connected to a DIN socket where provision is made for earthing the cable screen.

RF tuning

At medium and even moderately high frequencies, no improvement in performance will be achieved by introducing a stage of RF amplification ahead of the mixer. It is only when
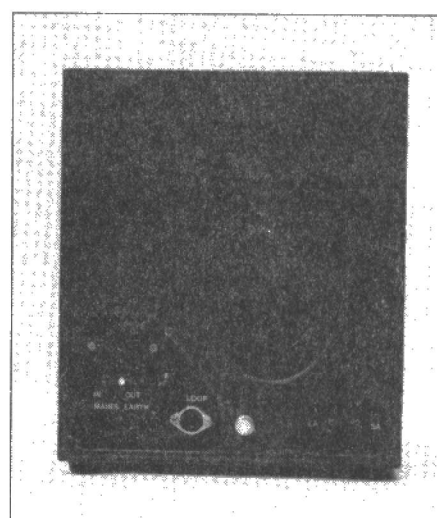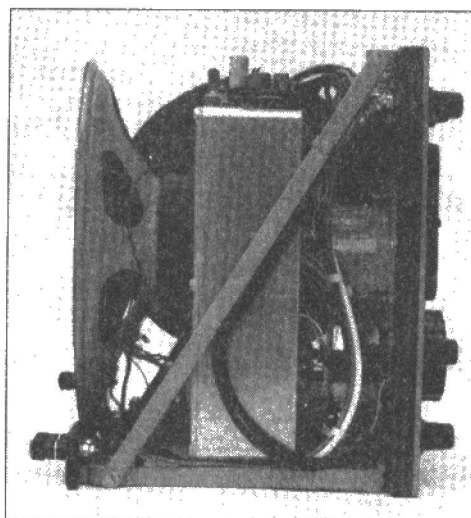
using inefficient aerials that this kind of stage can be justified, and even then the gain must be carefully controlled. In other circumstances, signal amplification ahead of the mixer will increase the possibility of blocking and cross modulation.

A good front-end selectivity will, on the other hand, narrow the bandwidth of frequencies accepted by the receiver, and do help prevent weak signals being swamped by strong ones. It will also improve signal-to-noise ratio before any mixing or amplification takes place, and significantly reduce the risk of spurious responses that can be generated within the receiver itself.

Additional pre-mixer selectivity is provided in this design by the bandpass circuit formed from L1, L2, the 'top' coupling capacitor C2, and the associated tuning capacitors, C3 and C4. Arrangements of this kind were common in high-quality valve radios designed for connection to 'long wire' aerials. The inclusion of a four-gang tuning capacitor may seem extravagant, but this component is obtained by linking two inexpensive polythene dielectric variable capacitors. Full details are given later in this article.

Front-end AGC

Some means of automatically reducing the level of strong signals before they reach the mixer is desirable, and this function is performed by Q1, which acts as a voltage-controlled resistor in the low-impedance coupling link between the bandpass filter and the input tuned circuit of the mixer.

When a FET is used in this way, the gate voltage varies the resistance of the drain-source channel from around a hundred to several thousand ohms. Resistance increases as the gate becomes more negative with respect to the source, with most of the change taking place between -1 and -3V. Signal input must not exceed 500mV or linearity will suffer, but voltages of this order are not likely to be developed across low impedance coupling windings at this point in the receiver.

The potential divider network formed by R11 and R12 enables the positive voltage on the source to be set between zero and a little in excess of 1V, determining the threshold at which the front-end AGC starts to operate. R10 isolates the signal path, C7 acts as a bypass capacitor, and C6 and C8 are coupling and DC blocking capacitors.
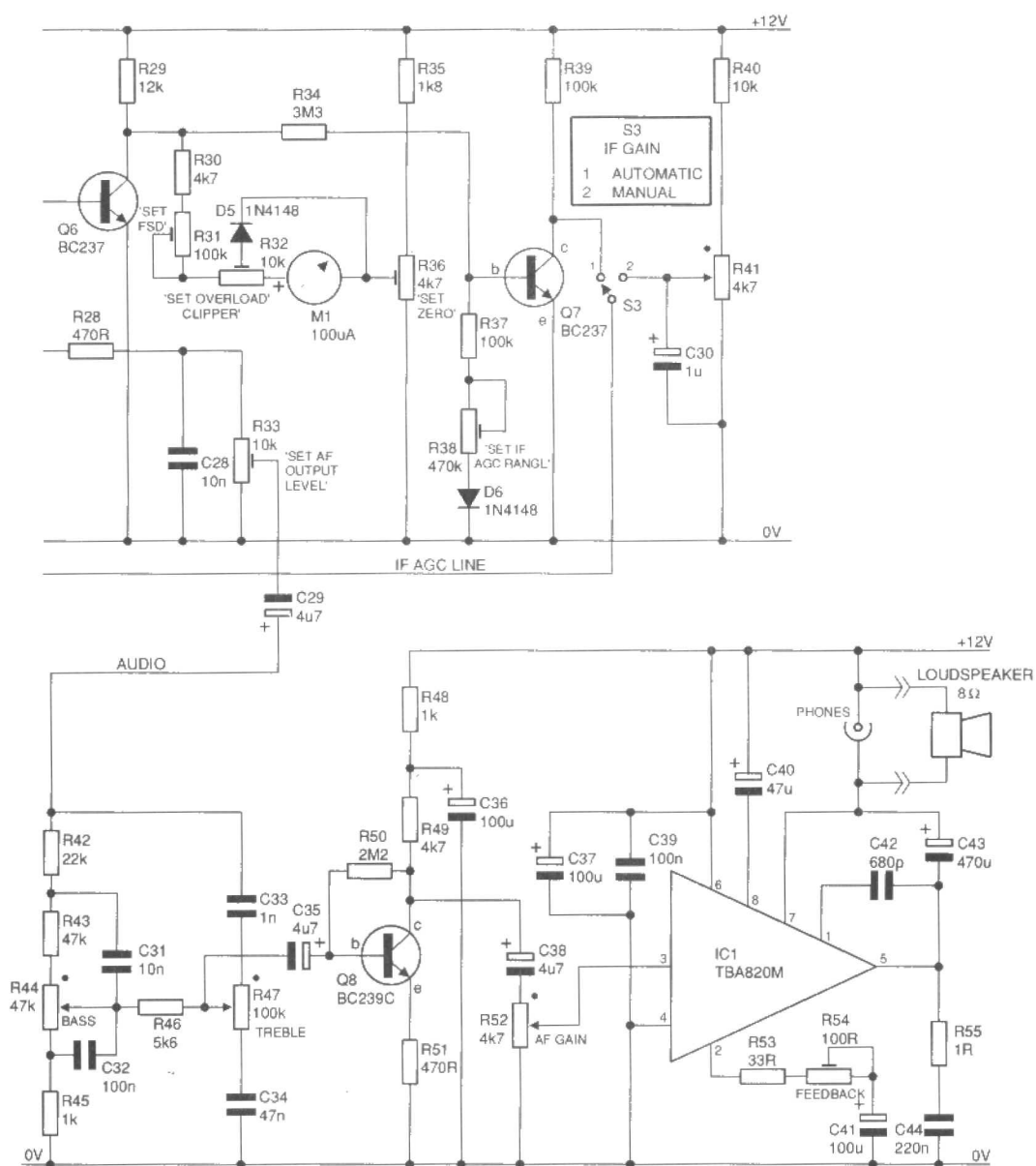

Figure 1c/d: the signal strength meter and AGC amp stages, manual IF gain control and (lower) the tone control and audio output stages
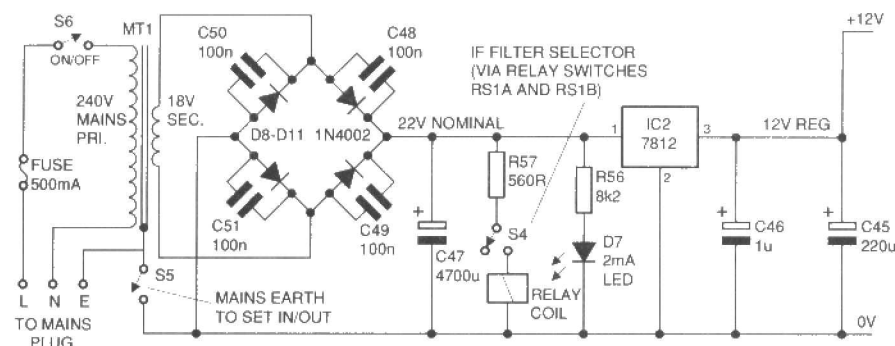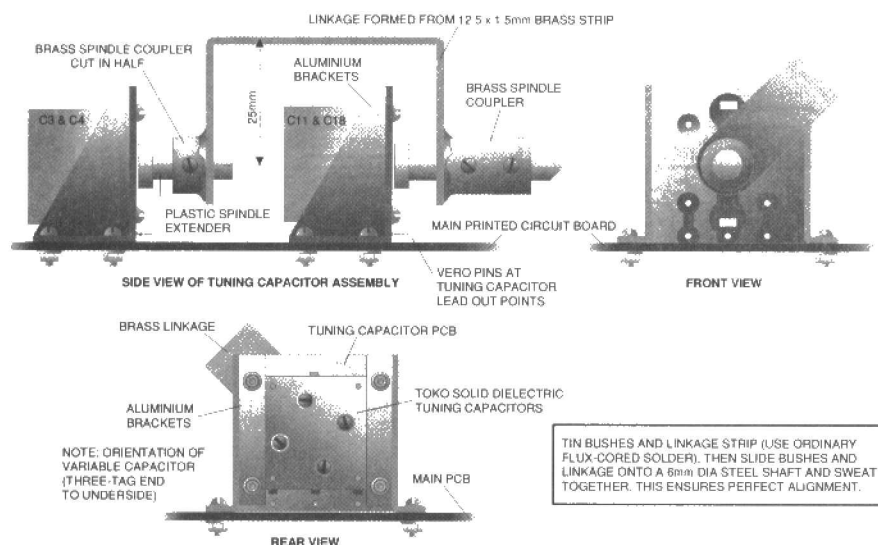
Figure 1e: the power supply stage

Figure 2: linking two variable capacitors to form a four-gang unit: tin bushes and linkage strip (use ordinary flux-cored solder), then slide bushes and linkage onto a 6mm diameter steel shaft and sweat them together. This ensures perfect alignment.

The control voltage is derived directly from the negative output of the diode detector D4, and is applied to the gate via potentiometer R13, which permits adjustment of the AGC range. R27 and C9 are decoupling components.

In practice, good results are obtained with most specimens of 2N3819 when R12 sets the source at 1V and R13 is adjusted for maximum input. These pre-sets do, however, enable the AGC characteristics to be altered to suit individual preferences.

Reducing the setting of R13 with the receiver tuned to a very strong signal will reveal how effective this arrangement is in preventing overload.

The mixer

The dual-gate mosfet mixer circuit configured around Q2 is conventional. Signal voltage developed across the tuned circuit formed by L3, C10 and C11 is applied to gate1, and the local oscillator voltage to gate2. Source bias resistor R16 is bypassed by C14, and bias is applied to gate2 by connecting it to the source via signal isolating resistor R14.

The combination of signal and local oscillator voltages is developed across the primary winding of IFT1, which, together with the filters and the other IFTs, is tuned to 455kHz (the difference between the two frequencies). R15 and C12 decouple the stage from the supply. C13 is a DC blocking capacitor.

Low cost and ease of application have made dual-gate mosfet mixers a popular choice for higher performance

receivers. Noise and intermodulation distortion are acceptably low, and they provide some conversion gain.

The local oscillator

Another FET, Q3, is the active device in the Hartley oscillator circuit, and L4, C15 and C18 are the frequency determining components. C16 and trimmer, C17, act as a padder, reducing the capacitance swing of C18 in order to make the oscillator track at 455kHz above the signal-frequency circuits (figure 1b)

Feedback is applied by grounding the source of the transistor through a coupling winding on L4. C19 connects the tuned circuit to the gate, and R17 ensures correct biasing. R18 and C20 decouple the stage from the supply.

Dual gate mosfet mixers require a local oscillator injection in the region of 1.8V RMS in order to ensure best blocking and intermodulation performance. The chain of diodes, D1-D3, from the gate of Q3 to the 0V rail, holds the oscillator output constant, at this voltage, over the entire swing of the tuning capacitor. An oscilloscope check confirmed that the quality of the wave form is not affected by this regulating measure, which helps to keep receiver sensitivity uniform over the entire tuning range.

The IF filters

The four IF tuned circuits will not, on their own, ensure a high enough degree of selectivity for our purpose, and switched filter elements are placed in the IF strip immediately after the mixer. F1 is an inexpensive mechanical filter with a bandwidth at the 6dB down points of 4kHz. F2 is a high-performance ceramic filter with a bandwidth of 2.6kHz. The latter may seem very narrow for broadcast transmissions, but its use dramatically reduces noise levels under difficult conditions, and receiver tuning can be set to the upper or lower side band in order to optimise reception. If the filter is used in this way, the quality of the audio is still entirely acceptable.

Filter switch wiring must, of course, be very short and direct. Switching diodes are invariably used in commercial receivers, but here a signal-switching relay is mounted close to the relevant components. This is simpler, less expensive, and probably takes up less space on the PCB. When its coil is energised, change-over contacts bring the narrow filter into circuit.

IFT1 and IFT2 act as matching transformers for the filters, which have port impedances ranging between 1 and 2k. Connection of Q2 and Q4 to the tuned windings of these transformers has been deliberately made less than optimum in order to increase the stability margin of the receiver. A better match would be obtained with the drain of Q2 taken to a tapping and the gate of Q4 connected across the entire winding. Connected in this way, however, there is a tendency to instability and, as there is gain to spare, I adopted the arrangement used here.
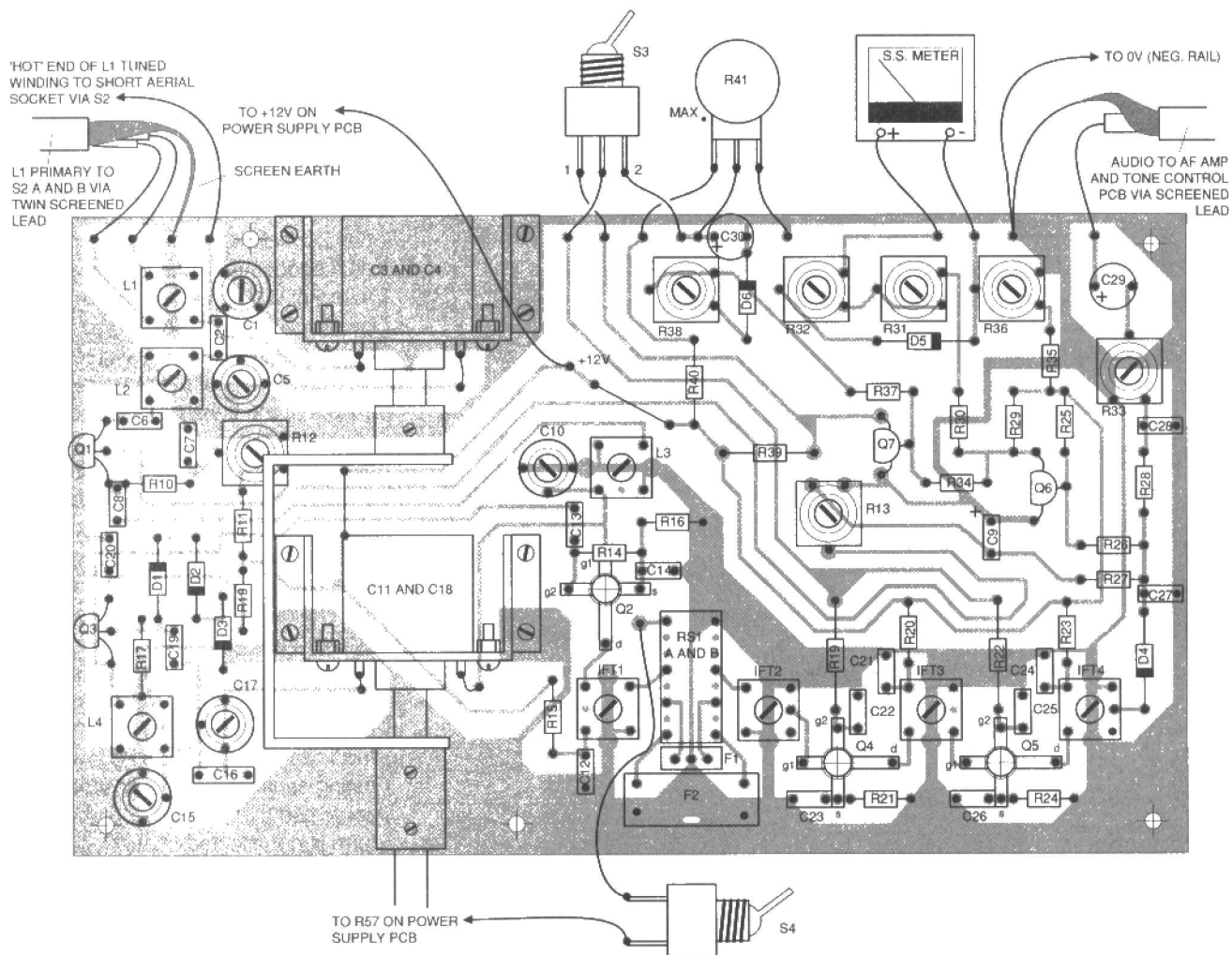
Figure 3: the component layout of the RF, IF and Detector stages PCB

The IF amplifier

Q4 and Q5 are almost identical amplifier stages coupled by IFT3. Source bias resistors R21 and R24 are bypassed by C23 and C26, and the gain of the circuit is controlled, either manually or automatically, by varying the voltage on the second gates of the mosfets. R19 and R22, together with capacitors C22 and C25, are AGC line decoupling components, and R20 and R23, along with C21 and C24, decouple the IF stages from the supply line. A tapping on the tuned winding of IFT4 matches the final stage to the diode detector.

The detector

Signals are demodulated by the germanium diode D4. C27 acts as the detector reservoir capacitor, and R28 and C28 filter out residual RF. R28 and pre-set potentiometer R33 act as the diode load, and the potentiometer also permits adjustment of the audio output level.

Signal strength meter and AGC amplifier

As signal level increases, the DC voltage developed across C27 becomes increasingly negative, reducing the current flowing through Q6 and thereby increasing the voltage at its collector. The amplified voltage swing is displayed by moving coil meter M1, in order to provide a comparative indication of signal strength (figure 1c/d).

Potentiometer R36 enables the meter pointer to be set at zero under no-signal conditions; R31 adjusts meter sensitivity, and R32 sets the level at which D5 begins to conduct, compressing the high end of the scale and preventing meter overload on strong signals. The signal strength meter circuitry will, of course, function with the IF AGC system switched off.

The second gates of IF transistors Q4 and Q5 have to be held at around 4V to ensure maximum gain under weak signal conditions. A second DC amplifier, Q7, inverts the output of Q6 to provide the necessary control voltage, which is set by potentiometer R38 to fall from 4V to near zero as the signal level increases. D6, at the 'bottom end' of the bias chain, stabilises Q7 against thermal drift.
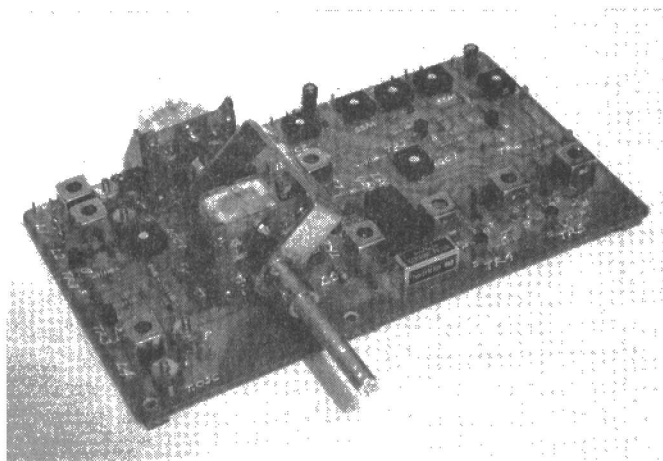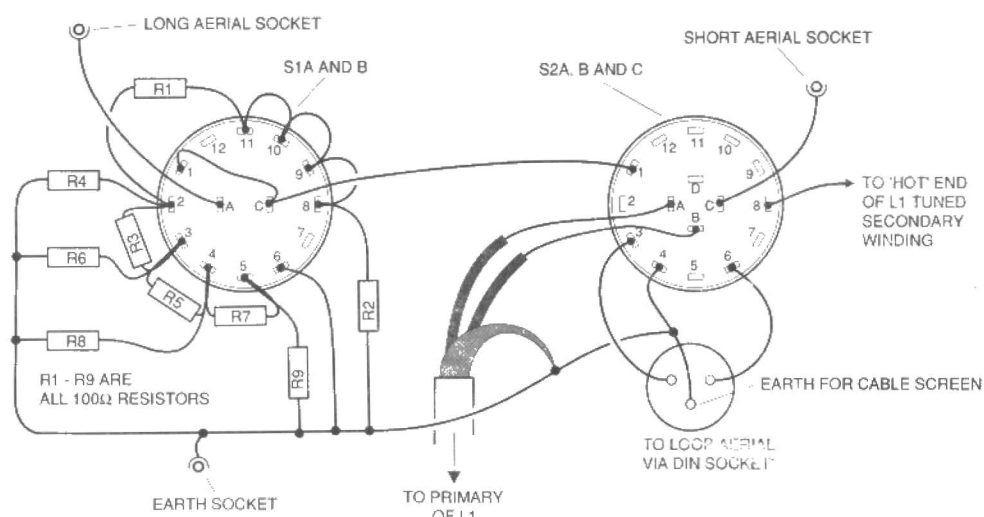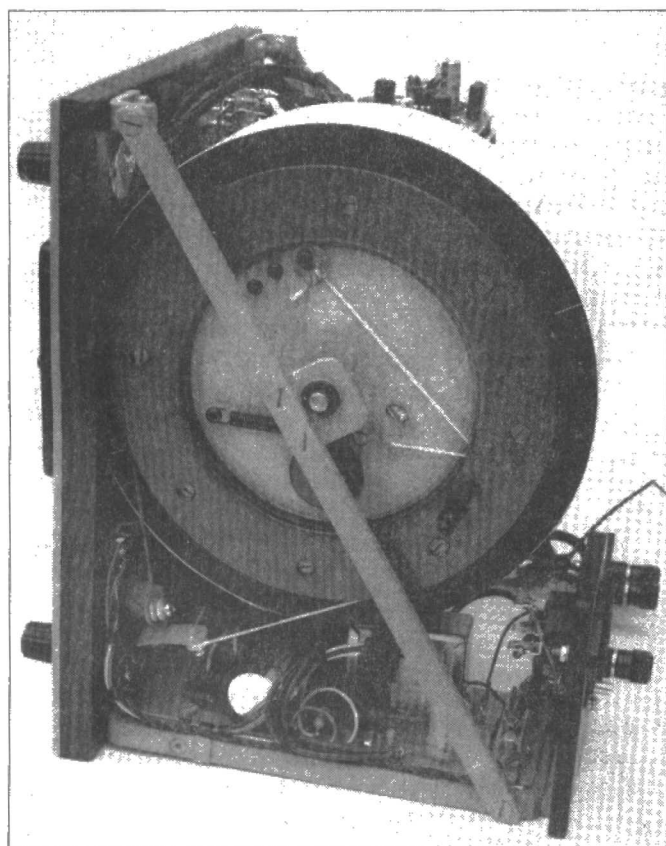
Figure 4: details of the attenuator and aerial switch wiring (tag numbering is for the switches specified)

Manual IF gain control

The ability to switch off the AGC system and put the gain of the IF amplifier under manual control is a desirable feature, enabling receiver noise to be kept at the lowest possible level. When gain is controlled automatically, it rises to maximum in the absence of a signal, and the inevitable hiss of band noise can be tiresome. Turning IF gain well down results in almost complete silence between stations as the receiver is tuned across the band, making it more pleasant to use when maximum weak-signal sensitivity is not required. The front-end AGC system is, of course, still operational, and this prevents large swings in output.

Switch, S3, connects the AGC line to the collector of Q7

when automatic control is required, or to the slider of R41 when gain is to be set manually. R40 fixes the voltage across R41 at around 4V to ensure the necessary control range. C30 prevents potentiometer noise.

Tone control stage

In a receiver of this kind, tone controls are often used to increase the clarity of weak signals by broadly peaking AF response around 1kHz. A great many music stations can, however, be received at good entertainment quality, especially if a decent speaker is fitted, and the tone can be adjusted, which many listeners will find welcome.

The design uses a conventional passive network. Centred around potentiometers R44 and R47, the various component values have been tailored to suit the audio output from the diode detector, which is made a little bass heavy by the enhanced selectivity. Q8 overcomes signal losses in the tone control network. The omission of a bypass capacitor across its emitter resistor results in negative feedback, which reduces stage gain to around ten times. This is perfectly adequate. R49 is the collector load, base bias is determined by R50, and R48 and C36 decouple the stage from the supply.

The audio output stage

Power output is provided by an inexpensive TBA820M audio amplifier IC which can deliver 2 watts into an 8-ohm load when connected to a 12V supply. Pre-set R54 controls an internal feedback network and varies the gain of the device. The value of capacitor C42 has been chosen to limit the frequency response of the amplifier to 7kHz (stations on the medium wave band do not broadcast audio frequencies higher than this).

The input pin of the amplifier is connected to the slider of the AF gain control R52. Amplifier output is coupled to the speaker by C43, and R55 and C44 form a Zobel network which ensures stability under different loading conditions. C40 is a supply voltage ripple rejection capacitor, and C37 and C39 prevent the impedance of the power supply leads causing RF or AF instability.

A switched stereo phone jack is provided. Connecting it in the manner shown puts the two earpieces in series. The resulting 60 ohm load limits the output of the amplifier, and sound levels on the 'phones are kept at a comfortable level.

Figure 5: the audio amplifier and tone control PCB component layout

The power supply

Although the current drawn by the receiver is comparatively modest, a mains power supply with a regulated output ensures consistent performance, and is far more economical than batteries. The power supply circuit shown here is quite conventional. Diodes D8 - D11 are arranged in a bridge to give full-wave rectification of the 18V AC supplied by the mains transformer MT1. Approximately 22V is developed across the reservoir capacitor C47. Capacitors C48 - C51 prevent modulation hum, and C46 is a tantalum capacitor, included to bypass noise generated by the 12V regulator IC2. Supplies to the LED indicator and the relay coil are taken directly from the rectifier output, and the values of R56 and R57 assume the use of the specified relay and low-current LED. If different components are used, these values may need changing.

A low-current internal fuse is included, and the mains earth is connected to the core of the transformer as a fault protection measure. Connecting the mains earth to the 0V line of the receiver can greatly improve reception if an independent earth is not available. Some transformers are available with shield between the mains winding and the secondary winding, and this can significantly reduce interference if grounded. Unfortunately, using the mains earth in this way sometimes results in the injection of heavy electrical interference, and S5 enables it to be quickly disconnected if this problem is suspected.

This is a mains project. If you are not yet confident in mains construction, seek the assistance of someone who has the relevant experience, or consider using the battery option described in the next section.

Next month

In the second part of this project the author will describe how to simplify the receiver design for those who prefer to start with a less sophisticated design, and describe the construction of the circuits described this month.

Figure 6: the component layout of the power supply PCB

Resistors

(All 0.25W, 5 percent tolerance, or better)

R1-R9, R16	100R
R10	12k
R11	27k
R12	4k7 pre-set
R13	1M pre-set
R14	100k
R15, R18, R20	330R
R17	120k
R19, R23, R42	22k
R21, R28, R51	470R
R22	22k
R24	150R
R25, R50	2M2
R26	220k
R27, R37, R39	100k
R29	12k
R30, R49	4k7
R31	100k pre-set.
R32, R33	10k pre-set.
R34	3M3
R35	1k8
R36	4k7 pre-set
R38	470k pre-set.
R40	10k
R41	4k7 linear potentiometer.
R43	47k
R44	47k linear potentiometer.
R45, R48	1k
R46	5k6
R47	100k linear potentiometer.
R52	4k7 log potentiometer.
R53	33R
R54	100 linear pre-set.
R55	1R
R56	8k2 (see text).
R57	560 (see text)

Capacitors

All 16V working or greater, unless otherwise stated.
All electrolytics radial lead, unless otherwise stated.

C1, C5, C10, C15, C17	2 - 22pF miniature film-dielectric trimmers
C2	10pF ceramic
C3, C4, C11, C18	2 x no. 355pF twin-gang (fm sections not used), Toko Polyvaricon tuning capacitors.
C6, C8, C13, C27-28	10nF ceramic
C7, C12, C14, C20-26	100nF ceramic
C9,	1uF tantalum
C16	220pF close tolerance ceramic
C19	10pF ceramic
C29, C35, C38, C40	4u7 electrolytic
C30	1uF electrolytic
C31	10nF mylar
C32	100nF mylar
C33	1nF mylar
C34	47nF mylar
C36, C7, C39, C41	100uF electrolytic
C42	680pF ceramic
C43	470uF electrolytic
C44	220nF polyester
C45	220uF electrolytic
C46	1uF tantalum
C47	4700uF electrolytic, 35V working, axial or radial lead
C48 - C51	100nF ceramic, 50V working

Inductors and filters

All Toko 10EZ types

L1 - L3	RWR331208N2 330uH MW RF coils (red core)
L4	YRCS18576AQ 100uH MW oscillator coil (green core)
IFT1	RMC41996N Filter matching transformer (red core)
IFT2	RMC41997N Filter matching transformer (blue core)
IFT3 - IFT4	RZCSA9620DC 3rd IF/Det' (black core)
F1	Toko CFM2-455A 4kHz mechanical
F2	Murata CFM455J1 2.6kHz ceramic

Semiconductors

IC1	TBA820M
IC2	7812 12V regulator
Q1	2N3819
Q2	BF981
Q3	2N3819
Q4,Q5	BF981
Q6,Q7	BC237
Q8	BC239C
D1-3, D5, D6	IN4148
D4	OA91
D7	2mA LED
D8-11	IN4002

Switches and relays

SI	Lorlin 2 pole, 6 way, rotary
S2	Lorlin 4 pole, 3 way, rotary
S3	Single pole, double throw toggle switch (on-on type)
S4, S5	Single pole, single throw toggle switch (on-off type)
S6	AC mains rated, singe pole single throw toggle or rotary switch
RS1	Double pole, double throw, signal switching relay with 12V coil

BT equivalent type by Fujitsu. (Maplin order code: DC80B)

Other components

MT1   9-0-9V secondary (used as 0 - 18V) miniature transformer, rated at 250mA. Primary to suit mains voltage

Printed circuit board materials, Vero pins, 8 and 16 pin dil IC holders. Fuse holder and 500mA fuse, mains chassis plug and line socket. Aerial and earth terminals, 3 or 5 pin DIN plug and socket for loop aerial. Spindle extenders, brass spindle couplers, 305mm length of 1.6 x12.7mm brass strip; 6.3 mm diameter steel shafting. Slow motion tuning drive and dial making materials. Control knobs and LED indicator bezel. 50 or 100uA moving coil meter. Heat sink for regulator IC (TO220 style device). Nuts, bolts and washers. Hook-up wire. Loudspeaker, 8 ohms impedance. Proprietary metal case or case-making and finishing materials.

All parts are of widely available types. Toko and Murata parts and some other specialised parts are available from Cirkit (see section Components, in Part 2).

ETI Minute Minder

Bleeps track of time in the car, darkroom or kitchen. By Terry Balbirnie.
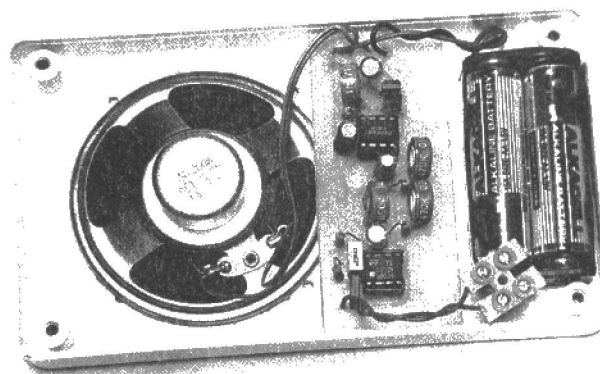
his useful little gadget will help you to keep check on the passage of time without having to look at a clock or watch. It works by giving a short bleep every 15 minutes and a long one on the hour. It could be particularly useful during a car journey since the eyes need not be taken off the road to know how much time has elapsed since it was last reset. You will be able to use the Minute Minder to check that you are on time for an appointment or simply as a reminder to stop to make a phone call or take a rest.

The circuit may also be used for general purposes around the house possibly with modified operating times. It might be found handy for the kitchen or photographic darkroom, for example. For such applications, it could be powered from a commercial dc plug-in adaptor. Where no mains supply exists, it would also be possible to use batteries and more will be said about this later.

Flashing indicator

The circuit is built in a small plastic box. On the front panel is an on-off switch, an LED indicator and a push button reset switch. While the unit is switched on, the LED flashes about once per second. The reset switch enables the timing to be started from the beginning as required.

It would be a simple matter to modify the circuit to give signals at longer or shorter time intervals - for example, at one minute, two minutes, three minutes and the long one at four minutes. Details for doing this are given in the text. This idea could be useful in the home for keeping a check on the length of a phone call - especially one to a mobile or overseas destination. Note however that, although the periods may be set from a few seconds to several hours, they must all be the same length. It would not be possible to provide a signal at say, 2 minutes, 5 minutes, 8 minutes and 12 minutes.

The circuit is not designed to be highly accurate - it is controlled by pulses from a simple astable and there is no quartz crystal of the type used in a modern clock or watch. However, it will be sufficiently accurate for the purposes mentioned earlier. In theory, there should be no change in the timings with applied voltage but, in fact, there is a small effect. In tests on the prototype, there was a variation of about 4 seconds per hour over the range 11V to 13V. There is also a small drift in the timings with temperature. Over the range 5 to 20 degrees Celsius this was also about 4 seconds per hour. In practice, when used in a car, the voltage and temperature will be reasonably constant and the timings will be within a few seconds per hour. When used with a stabilised plug-in supply in the constant temperature of a centrally-heated house, the
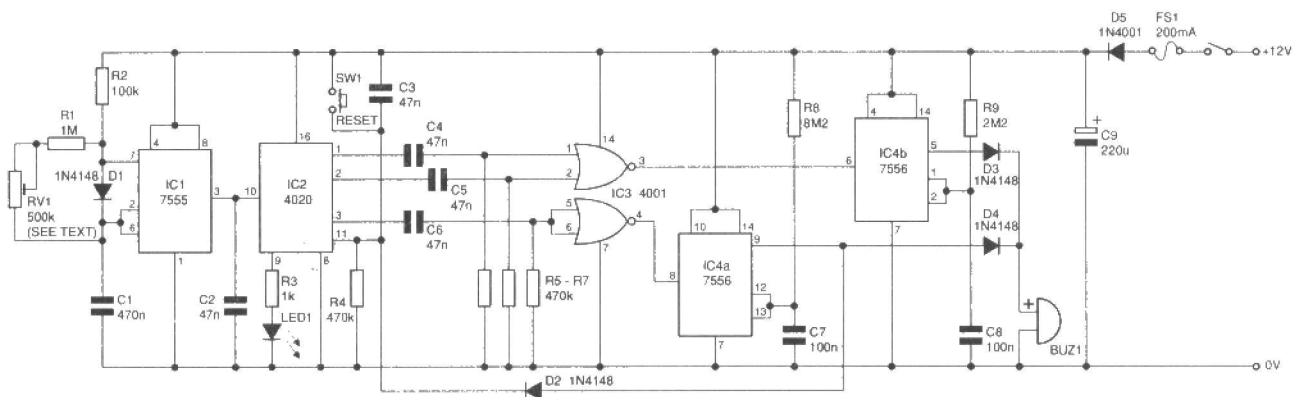
Figure 1: the circuit diagram of the Minute Minder

timings might be even closer. The accuracy largely depends on the temperature coefficients of the components used (how much their values change with temperature) and may not be the same as in the prototype. This circuit should not be constructed where accurate timings are essential.

How it works

The complete circuit for the Minute Minder is shown in figure 1. The supply is connected via on-off switch S2, fuse F1 and diode D5. This latter component provides reverse polarity protection and also operates in conjunction with capacitor C9 to smooth the supply. Smoothing is particularly important when the circuit is powered by the car electrical system.

The astable section, which provides the basic timing pulses, comprises IC1 and associated components. The time period is dependent on the values of R2, R1, RV1 and C1 and at the end of construction, RV1 will be adjusted to give pulses at 0.44 second intervals (about 2.3 pulses per second or 2.3Hz) and these appear at pin 3. The reason for this rather strange figure will become apparent presently. Using a short basic time period rather than, say, one of 15 minutes avoids the need for very high values of timing components. In particular, requiring a large value for C1 would almost certainly involve using an electrolytic capacitor. This would not be satisfactory because such components have a very wide range of tolerance. It is found that the value changes greatly with temperature and other factors and this would be reflected in highly inaccurate timings. Diode D1 shortens the length of the pulses compared with the space between them and the result is effective for processing by the next section of the circuit..

Slow pulse

The pulses referred to above are fed to the clock input (pin 10), of 14-stage binary counter, IC2. C2 bypasses the electrical noise which is often picked up along the inter-connecting PCB track and which could result in false pulses and erratic timings.

On the arrival of pulses to IC2, each of its fourteen outputs (Q1 to Q14) go high in various combinations to register the total number received in binary. Note that most of the outputs are unused and only Q1, Q12, Q13 and Q14 (pins 9, 1, 2 and 3 respectively) are shown in the diagram. The result of the first few clock pulses is shown in Table 1 (it would be impractical to show the entire counting cycle due to the large number of lines involved). It can be seen that the second output (Q2) goes high on the second pulse, the third one (Q3) on the fourth, the fourth one (Q4) on the eighth and so on. By extending this reasoning, it can be deduced that output Q12 will go high on the arrival of 2048 pulses (which corresponds to 15 minutes at a clock rate of 1 every 0.44 seconds), Q13 on 4096 pulses or 30 minutes and both Q12 and Q13 on 6144 pulses or 45 minutes. The final output, Q14, will go high on receiving 8192 input pulses or 1 hour. It will now be clear why the clock rate is set to 1 pulse every 0.44 seconds. Left to itself, counting would proceed until all outputs had gone high and the cycle would repeat. However, in this circuit, the counter is reset on the hour and begins again. How this is achieved is explained later.

Output Q1 is used to feed light emitting diode LED1 via current-limiting resistor, R3. Referring again to Table 1, it can be seen that this will operate at one-half of clock frequency - that is, at 0.88 second intervals. The LED thus acts as a flashing indicator light, as a check that the astable is working and will be used as an aid to adjusting the timings at the end.

Table 1: The results of the first few clock pulses of IC2 (see text).

Q	14	13	12	11	10	9	8	7	6	5	4	3	2	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	0	0	0	0	0	0	0	0	0	0	0	1	1	0
	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	0	0	0	0	0	0	0	0	0	0	1	0	1	0
	0	0	0	0	0	0	0	0	0	0	1	0	1	1

At the gate

At the times when Q12, Q13 or both Q12 and Q13 go high, a pulse is transferred through capacitor C4 or C5 to one or both inputs (pins 1 and 2) of 2-input NOR gate, IC3a. IC3a is one section of a quadruple 2-input NOR gate chip - that is, the ic contains four identical gates. Only two of them are used here. The function of the other one, IC3b will be explained presently. The truth table for a NOR gate is shown in figure 2 and it will be seen that its output is low if one or both inputs is high. Where both inputs are low, the output is high. In the absence of any pulse, IC3a inputs will be kept low by pull-down resistors R5 and R6 so the output, pin 3, will be normally high.

On the arrival of a high pulse to either or both inputs, the output will pulse low. Capacitor coupling between IC2 outputs and IC3 inputs is necessary since, otherwise, on the transitions between Q12 and Q13 going high, no change would be seen by IC3 output (it would remain low all the time) since, as far as it is concerned, one of its inputs would have remained high. The capacitors overcome the problem by allowing the active IC3 input to go low again soon after the arrival of each pulse.

Figure 2: truth table for the NOR gate:

inputs		output
0	0	1
0	1	0
1	0	0
1	1	0

When a low pulse is produced at IC3 pin 3, a similar state is transferred to IC4b trigger input, pin 6. IC4b is one half of a dual timer integrated circuit and this, together with the other section (IC4a) are connected as monostables. Thus, when triggered by such a low pulse, the output (pin 5) will go high for a certain time then revert to low. Note that it is a characteristic of this type of device that it is triggered by a low pulse - a high state applied to the trigger input has no effect. The time period of IC4b is determined by the values of R9 and C8 and with the values specified will be about 0.25 seconds. The output signal is passed through diode D3 to the buzzer, BUZ1, which therefore emits a short bleep.

Re-setting the counter

As explained previously, Q14 (IC2 pin 3) will go high after one hour. A high pulse is then passed through capacitor C6 to the inter-connected inputs of IC3b which is one of the other NOR gate contained within IC3. The coupled inputs give the effect of

a NOT gate so the high pulse is converted into a low one and is provided at the output, pin 4. This is then applied to IC4a pin 8 which is the trigger input of the other monostable. Since resistor R8 has a value of approximately four times that of R9 while C7 is equal in value to C8, the time period of IC4a is about four times longer than that of IC4b - that is, about 1 second. This is provided at pin 9 and is passed on via diode D4 to the buzzer. Thus, on the hour, although a short pulse is also given by IC4b, the longer one keeps the buzzer sounding for the extended time. The effect is that the buzzer gives three short bleeps then a long one at the specified time intervals.

When the one-hour bleep is produced and IC4a output (pin 9) goes high, a high state is also passed via diode D2 to IC2 reset input, pin 11. This returns the counter to zero and the cycle repeats. When the circuit is switched on, capacitor C3 charges up through R4. This applies a brief high state to pin 11 and ensures that the counter begins at zero. Pin 11 is kept normally low by R4 and this prevents false resetting. The counter may be reset manually by pressing switch SW1 momentarily and this also applies a high state to pin 11.

Time settings

To reduce the timings outside the range of RV1 adjustment, the value of C1 may be reduced in proportion. To increase the timings, either C1 or R1 could be increased in value. For the reasons given earlier, it is necessary to avoid the use of an electrolytic capacitor for C1 and this, in practice, gives an upper limit of about 10mF. On the whole, it would be easier to raise the value of R1 or to do this in combination with a modest increase in C1 if necessary.

To increase the length of the bleep times, the shorter one could be adjusted by increasing the value of R9 in proportion and vice versa. For the longer bleep time, similar changes may be made to R8.

Construction

The PCB component layout is shown in figure 3. Begin by drilling the two fixing holes, mounting the four ic sockets and soldering the three link wires in place. Attach the two-section piece of screw terminal block, TB1. Follow with all capacitors and resistors (including preset RV1). Do not use an ordinary (single turn) trimmer for RV1 - this would be much too difficult to adjust correctly. It is necessary to use a multi-turn type (a 12

turn unit was used in the prototype but others would be equally suitable). Some of these have an in-line pin arrangement while others have them set out in the form of a triangle. There are two holes provided on the PCB for the centre pin and the appropriate one should be used. Note that the polarity of C9 must be observed (this is clearly marked on the body). With some specimens of C9, and if height is at a premium, it may be necessary to bend the end leads at right angles and lie it flat on the PCB. Add the five diodes and the buzzer, again, taking care over the polarity of these components. Bend the LED leads through rights angles and solder them to the PCB (observing the polarity) so that the body lies about 5mm above it. Complete construction of the PCB by soldering 5cm pieces of light duty stranded wire to the points labelled "S1".

Prepare the box by drilling holes in the base to correspond with the fixing holes in the circuit panel. Allow sufficient space to the right of the PCB for the fuse holder and on-off switch (see photograph). Measure the position of the LED and drill a hole to correspond (see later if the circuit is to be battery-operated). In the prototype, a 3mm diameter hole was used and the LED leads adjusted so that it took up a position directly behind it. When considering this, think also about the positions of the two switches so that they will all end up at the same height and the layout will look neat. Drill the holes for the switches and for mounting the fuseholder. Measure the position of the buzzer and drill a hole in the lid for the sound to pass through. This should be a little larger than the hole in the buzzer. Drill a further hole to enable RV1 to be adjusted using a small screwdriver or trimming tool when the lid of the case is in position. Drill a hole for the input wires to pass through if the unit is to be operated from the car supply. If it is to be powered using a plug-in adaptor, drill a hole and fit a socket to match the plug on the unit. Mount the switches and fuseholder using the holes already drilled for the purpose. When considering the orientation of the on-off switch, remember that the buzzer will point downwards if the unit is to be mounted under the car dashboard. Connect the reset switch wires leading from the PCB to the push-button reset switch but do not wire up the on-off switch yet. Secure the circuit panel in position on the base of the box. Check that the holes for the buzzer and preset align correctly and make any adjustments as necessary.

Insert the ics into their sockets observing the orientation.
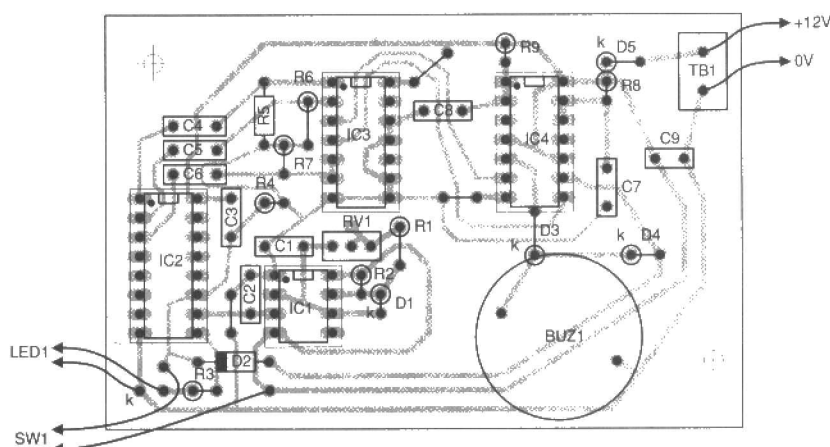
Figure 3: the component layout of the Minute Minder

Note that they are all CMOS components and, as such, are liable to damage due to static charge on the body. To avoid any problems, touch something which is earthed - such as a water tap - before handling the pins. Adjust RV1 so that the sliding contact is near the centre of the track. Do this by turning the screw one way until clicking is heard - this happens when the wiper is at the end. Count the number or turns until it reaches the other end then set it about half way between these extremes.

Testing and adjustment

It is convenient to test the circuit and make initial adjustments to RV1 using a 9V battery as a supply. Connect the positive terminal of the battery to the upper terminal of TB1 and the negative to the lower one - disregard switch SW2 and the fuse for the moment. As the supply is established, the buzzer may sound for about 1 second and the LED should be seen to be flashing at around once per second. Adjust RV1 until it flashes 68 times in 1 minute - clockwise rotation of the screw slows the pulses down and so extends the time period. Since this setting corresponds to 0.88 seconds per flash and this is equal to one-half of clock frequency, the clock must now be operating at 0.44 second intervals as required. Do not aim for great accuracy here - between 66 and 70 flashes per minute will be good enough for the moment. Check that the circuit may be reset by pressing switch SW1 for an instant. With approximate adjustment complete, connect one terminal of the on-off switch to one end of the fuse holder and connect the other end to TB1 top terminal. Complete construction by inserting the fuse.

If you are going to use the circuit in the car, you could plug it into the cigar lighter socket. However, a permanent connection is probably more satisfactory. To do this, locate a wire which is live only when the ignition is switched on. Make a connection to it using a snap-lock type connector and run a piece of light-duty automotive-type wire back to the unit. If this wire must pass through a hole in the car bodywork, it is essential to use a rubber grommet to prevent chaffing. Pass the wire through the hole in the box and solder it to the unused switch tag. Make an earth (car chassis) connection and connect it to the lower terminal on the terminal block. Leave some slack in the wires on the inside and provide strain relief by, for example, securing a cable tie tightly around them. Check that they cannot be pulled free. Secure the unit in position under the dashboard using adhesive fixing pads or self-tapping screws with the buzzer hole facing downwards. Check for correct operation and adjust the preset for the required accuracy. Note that the first operation after re-setting appears to be slightly less accurate than subsequent ones. When adjusting the circuit, therefore, do no keep re-setting it. Allow it to continue operating and make very small adjustments to the screw on RV1 to achieve the desired effect.

Stabilised supply

If you are using a plug-in adaptor as a power supply, use the stabilised variety having 12V output. There are two reasons for using a stabilised supply unit. Firstly, the fixed voltage output will result in more accurate timings. Also, the non-stabilised variety generally has a much higher output voltage than its nominal value when it is subject to only a small load as is the case here. This could damage the circuit. If the unit has a polarity reversal switch it is quite safe to try it one way and reverse it if the circuit does not work.

If you are using batteries as a power supply, it would be convenient to use a set of 6 "AA" size cells in a suitable holder giving a nominal 9V. However, the voltage will fall in the course of use and the timings may vary to some extent. It must be realised that the performance is not likely to be as good as when a plug-in adaptor supply unit is used. If using batteries, it would be a good idea to cut through one of the LED wires after the initial setting-up. This will prevent it from working and since the LED is responsible for most of the current requirement of the circuit, disabling it in this way will reduce the current to a low value - about 500mA. The battery pack should then give more than 1 year of service in occasional use.
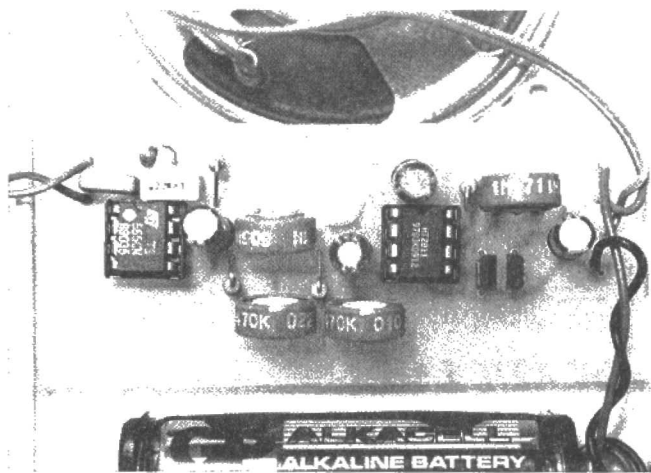
PARTS LIST for the Minute Minder

Resistors

R1	1M
R2	100k
R3	1k
R4, R5, R6, R7	470k
R8	8M2
R9	2M2
RV1	470k or 500k multi-turn preset trimmer (top - top adjustment type)

Capacitors

C1	470n
C2, C3, C4, C5, C6	47n
C7, C8	100n
C9	220m 25V axial electrolytic

All capacitors apart from C9 miniature metallised polyester with 5mm pin spacing.

Semiconductors

D1, D2, D3, D4	1N4148
D5	1N4001
IC1	7555
IC2	4020
IC3	4001
IC4	7556
LED1	10mm red LED

Miscellaneous

S1	Miniature push to make switch
S2	Miniature SPST toggle or rocker switch
BUZ1	PCB mounting buzzer - dc operation
F1	200mA 20mm fuse and chassis holder.

Printed circuit board. Plastic box size 111 x 57 x 22 mm approx. 8-pin dil socket, 16-pin dil socket, 14-pin dil sockets (2 off).

SPICED CIRCUITS

Circuit simulation with software, by Owen Bishop. This month, part 5 - More logic, and a design project

We ended last month by connecting a NOR gate to our 2-stage counter to detect count 00. The two outputs of the counter are connected to the inputs of a 2-input NOR gate. The output of the NOR gate goes high whenever both of its inputs are low, and this is supposed to happen when (and only when) when the counter is at stage 00. To check on whether this happens on not, we add this line to the netlist:

> nor 7402 a:b b:c out:d +v:pos gnd:GND

This calls on the library file 7402.lib which is a model of a 74HC02 2-input NOR gate. A plot of the counting sequence (figure 1) reveals something we had not intended. Recalling the circuit diagram from last month, a is the clock, b is the output from flip-flop 1, and c is the output from flip-flop 2. As expected, the output of the NOR gate (trace d) goes high when the counter is at stage 00 (b=0, c=0), but it also goes high (unexpectedly) for an instant as the counter changes from 01 (b=1, c=0) to 10 (b=0, c=1). When b changes from 1 to 0, this change in b triggers c to change from 0 to 1. But changes take time to propagate through the circuit so there is an instant when b has gone low but c has not had time to go high. Both are low together and the NOR gate detects this brief stage. This kind of behaviour is common in counters which rely on one stage to trigger the next, the

so-called ripple counters. In certain kinds of circuit, such as those driving LED displays, these inter-stage glitches do not matter because the eye is not fast enough to register the briefly incorrect display. But if the output from the counter is going to another logic circuit (such as our NOR gate) this can respond
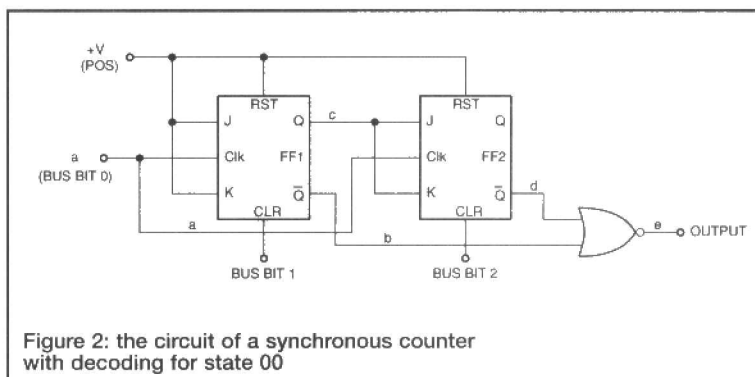
Figure 2: the circuit of a synchronous counter with decoding for state 00
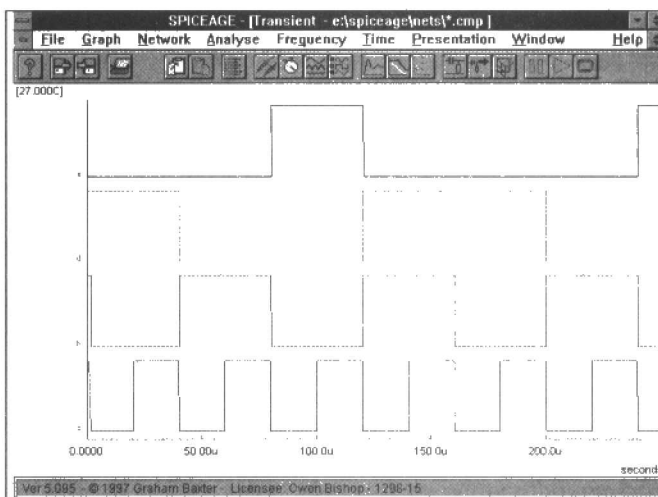
Figure 3: the output of the synchronous counter (figure 2) is free of glitches

fast enough to be affected by the erroneous signal.

The problem is overcome by using a synchronous counter, in which all the flip-flops are driven simultaneously by the same clock (figure 2). If we modify the netlist in this way, we find that counting proceeds without glitches appearing at the NOR gate (figure 3).

Logical primitives

Spice makes use of a number of built-in routines to
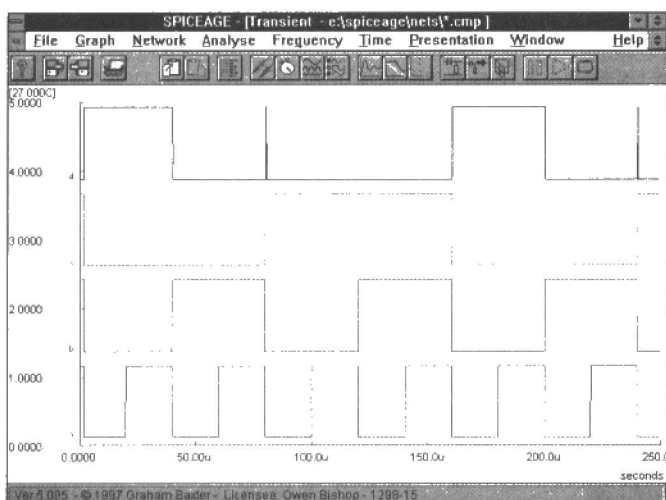
Figure 1: the output of the ripple counter described last month - complete with glitches

```
Synchronous counter
.SUBCKT     JKFF    q       q\      k       j       ck      pr\     clr\    +v      gnd
            NAND    g1      +out:NS1        -out:gnd        p3:+v   p4:q\   p5:j    p6:ck
            NAND    g2      +out:NR1        -out:gnd        p3:+v   p4:q    p5:k    p6:ck
            NAND    g3      +out:NQ         -out:gnd        p3:+v   p4:pr\  p5:NS1          p6:INQ
            NAND    g4      +out:INQ        -out:gnd        p3:+v   p4:clr\ p5:NR1          p6:NQ
            NAND    g5      +out:NS2        -out:gnd        p3:+v   p4:ick  p5:NQ
            NAND    g6      +out:NR2        -out:gnd        p3:+v   p4:ick  p5:INQ
            NAND    g7      +out:q  -out:gnd p3:+vp4:pr\    p5:NS2          p6:q\
            NAND    g8      +out:q\ -out:gnd p3:+vp4:clr\   p5:NR2          p6:q
            NOT     g9      +out:ick -out:gnd p3:+vp4:ck
.ENDS   JKFF
B       b1      +out:pos -out:GND       v=5.000000
Bus     clock   clock   p1:gnd p2:a     p3:clear1       p4:clear2       v=5.000000
X       jk1     p1:c    p2:b    p3:pos  p4:pos  p5:a    p6:pos  p7:clear1       p8:pos  p9:gnd  Mo=JKFF
X       jk2     p2:d    p3:c    p4:c    p5:a    p6:pos  p7:clear2       p8:pos  p9:gnd  Mo=JKFF
NOR     nor     +out:e  -out:gnd p3:pos p4:d    p5:b
```

represent frequently-used components such as resistors, capacitors and inductors. These are often referred to as primitives and serve their purpose well in the majority of circuits. Semiconductor devices such transistors are often represented by models of varying complexity, usually saved as library files, and consisting of circuits made up from the primitives. When we modelled the counter circuit (figure 2) we used the 7472 and 7402 library files. The 7472 files for the J-K flip-flops call in turn on other library files: 7410 for 3-input NAND gates, 7400 for 2-input NAND gates and 7404 for a NOT gate. These files contain descriptions of the gates modelled by the primitives - resistors, capacitors and diodes. As a result, the counter circuit as presented for analysis thus consists of very many resistors, capacitors and diodes built up into gates which are in turn built up into a flip-flop. It represents more or less exactly what is on the 74HC72 and 74HC02 chips, that is to say, a large number of actual resistors, capacitors and diodes fabricated on the chip in such as way as to produce the complex logic circuit.

If you build up and analyse logic circuits in this way, you will soon find that the number of components is reckoned in thousands and analysis time is prohibitively long. The analysis of logic circuits differs from that of analogue circuits because the key times are when gates are changing state. Unless a circuit is being driven at its maximum speed there are relatively long periods during which nothing is happening, while the circuit waits for the next change of state. You can see this if you watch the barmeter while the counter circuit is being analysed. The end of the bar moves a short way at high speed, then stands more-or-less still while gates change state, then skips along rapidly until the next change of state, and so on. SpiceAge has routines by which it recognises when nothing much is happening in the circuit and it automatically increases the sampling interval so as to get ahead quickly to the next point at which significant changes occur.

Then it slows down to compute the effects of these changes more precisely. This technique speeds up analysis of logical circuits but, in spite of this, they run very slowly if more than a few gates are involved. Recent versions of SpiceAge have included a new set of primitives for the logical operations AND, NAND, OR,
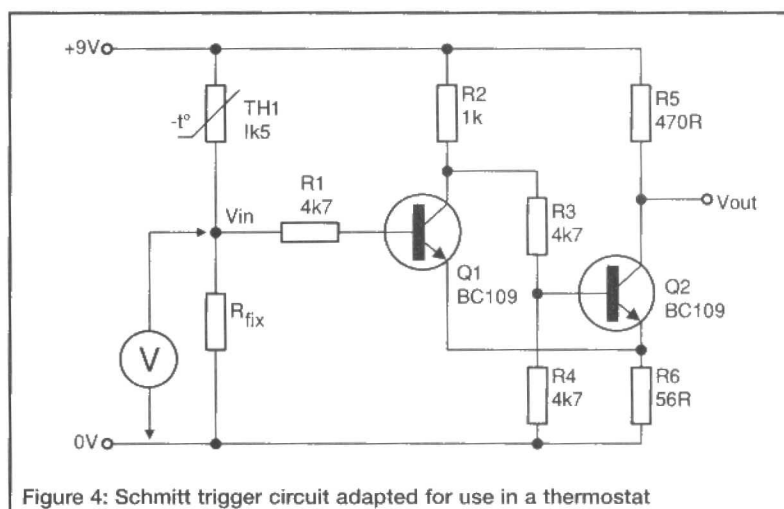
Figure 4: Schmitt trigger circuit adapted for use in a thermostat
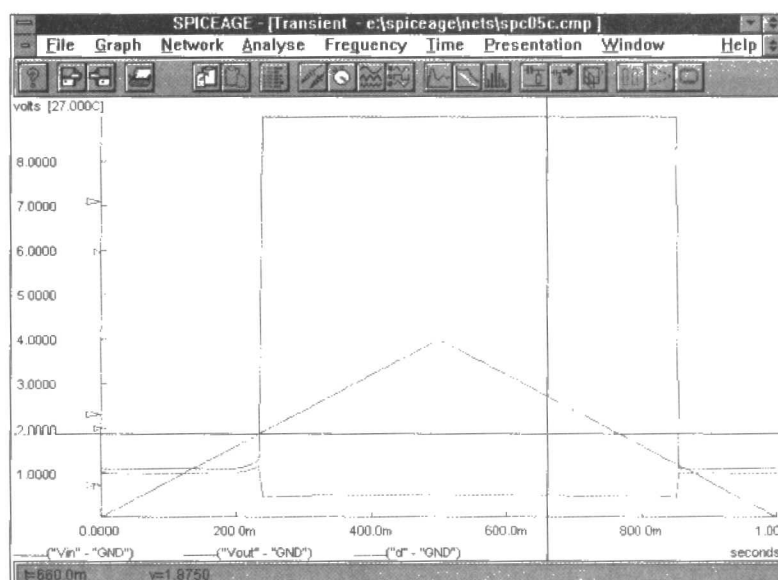
Figure 5: the behaviour of the thermostat circuit as input voltage is ramped up and down

NOR, NOT and EX-OR (exclusive-OR). Except for the NOT gate, the primitives have eight input pins. Pins that are not connected to are ignored. This provides the designer with an extensive range of logic gates not based on library files and without the need to have separate files to cover different numbers of inputs. Since we are starting with gates, instead of individual components (such as resistors) it is easier to compose the netlist and circuits are simpler to analyse. To explore this new feature, we 're-assembled' the synchronous counter circuit of figure 2, using the primitives instead of library files:

In this example, the flip-flop is defined as sub-circuit JKFF (we could have made it into a library file) which is called twice by using a Mo= statement in the later part of the netlist. The sub-circuit consists of eight NAND gates and one NOT gate, all of them primitives, and we have also used a NOR primitive on the last line of the netlist. When analysed, this netlist gave exactly the same plot as figure 2, but it took a very much shorter time to do it.

Design project

We set out to design a thermostat circuit based on a thermistor. It is to operate from a 9V battery and to hold temperature between 25degreesC and 32degreesC. One of the simpler circuits suitable for a thermostat is a Schmitt trigger, using two npn transistors (figure 4). The values, based on those obtained from a handbook, are the starting-point of the project. The input voltage (Vin) is produced by a potential divider consisting of a thermistor and a fixed resistor. As temperature rises, the resistance of the thermistor decreases and Vin increases. Knowing that the resistance of TH1 at 25degreesC is nominally 1500R, we use the formula on the data sheet to calculate that its resistance at 32desgrees is 1257R. Assume the resistance of Rfix is 22pR. Considering TH1 and Rfix as a potential divider, we calculate the input voltage as 1.15V at 25degreesC rising to 1.34V at 32degreesC. For convenience in the analysis we do not use TH1 and Rfix but use a ramp voltage generator instead. Actually we use a triangular wave generator, frequency 1Hz, amplitude 2V, offset 2V, phase delay 90 degrees, and run the transient analysis for 1 second. The result is a dual ramp waveform which rises from 0V to 4V in 0.5s then falls back to 0V in the following 0.5s. This simulates the thermistor increasing in temperature for 0.5s and cooling again for 0.5s.

Figure 5 shows the voltage input to the thermostat circuit and its output at the collector of Q2. At first, with 0V input, Q1 is off. This pulls up the voltage at its collector, turning Q2 on. This pulls down the output at the collector of Q2. When Q2 is on, the current through R6 produces 1V at the emitter. Consequently, the emitter of Q1 is at 1V and the base of Q1 needs to be at 1.6V before it can be turned on. The horizontal cross-hair in figure 5 shows that Q1 turns on as Vin reaches 1.875V (there is a voltage drop across R1). This turns Q2 off and Vout rises sharply to 9V. In one possible application of this circuit R5 is the coil of a relay controlling a heater. The action just described turns off the relay when the temperature exceeds the upper threshold. Turning off Q2 reduces the current through R6 and the voltage across it is reduced to

0.47V. This puts the base of Q1 at 0.47V and Q1 can not be turned off until its base falls below 1.07V, the lower threshold. Figure 5 confirms this, showing that Q1 is not turned off until Vin has reached 1.1713V. This illustrates the two features of a Schmitt trigger:

1. The circuit changes state very sharply, even though the input voltage rises and falls relatively slowly. This is an essential feature for a circuit that is to control a device such as a heater or a relay.
2. Once the circuit has been switched off at 32degreesC by a rising temperature, the temperature has to fall to 25degreesC before it is switched on again. This avoids a situation in which a circuit is triggering on and off every few seconds. The gap between the two thresholds is known as the hysteresis of the circuit. If you are following this project on a breadboard, now is the time to set up the circuit, measure the thresholds and find the hysteresis. Use a variable resistor to produce the varying input, as in figure 6.

The problem now is to match the values of Vin that we obtain from the simulation with the values we have calculated for the thermistor/Rfix potential divider. The first step is to try to match the hysteresis. For the thermistor it is 1.39 - 1.15 = 0.24V. For the circuit as shown by figure 5, it is 1.875 - 1.1713 = 0.704V. We have to reduce the hysteresis of the circuit. The main cause of hysteresis is the change in voltage across R6, so we can try the effect of reducing R6. Try altering the value of R6 in the netlist and re-running the transient analysis. On a breadboard, substitute a resistor of lower value for R6 and re-measure the thresholds. After trying various values, we arrived at 22R. Bearing in mind that the simulation is intended to represent a real circuit, we like to keep to standard E24 values as far as possible, to make it easier to translate it into hardware later. When R6 is 22R, the analysis produces a plot very similar to figure 5, but with different thresholds, 1.28V and 0.96V, giving a hysteresis of 0.32V. This is much nearer to the desired 0.24V but not near enough yet. We tried reducing R6 further but then ran into one of the problems inherent in simulators.

Convergence

Simulators operate on the principle of setting up a matrix holding voltage values for all the nodes of the circuit. Then the program runs around the matrix, calculating currents and seeing what effect this has on the voltages at connected nodes. Then it repeats, or iterates, the operation. Each time round, it modifies the voltages, and repeats this operation until the voltage changes between iterations are less than a predetermined minimum. It takes these voltages to represent the true state of the network at that instant. We say that it has converged on an instantaneous solution of the network. The circuit is active, of course, and there may be signal voltages present or capacitors which are charging, for example. An instant later, some of the voltages will have changed and the simulator has to repeat the iteration to converge on a new set of voltages for the next instant. This technique generally works well, but there are some kinds of network which make it fail occasionally.

The Schmitt trigger is one such network. In fact any network in which there is feedback is potentially a problem, particularly if the feedback is positive. Oscillators and certain kinds of amplifier can suffer from this difficulty. What happens is that, when the simulator tries to converge on a set of instantaneous voltages, some of the newly calculated voltages may depart further than before from their previous values instead converging ever more closely. When this happens, SpiceAge flashes a message - 'Changing damping strategy 1', usually followed after a while by 'Changing damping strategy 2'.

Even this approach may fail to bring about convergence and a final panel is displayed saying that it failed to converge and there may be no unique solution. All this time, you will note that the barmeter has stayed at the same level, indicating that virtually no progress is being made. When the final panel is displayed you are given three options, one of which is to ignore the message and carry on with the analysis. Perhaps we have been lucky but we have always found that pressing this button lets the simulator continue and (so far) produce a sensible result. When analysing this thermostat circuit convergence problems arise only when dramatic changes are occurring, that is, when the circuit is passing through the upper and lower thresholds. But convergence problems lead to long delays in the analysis and it is best to avoid them, if possible, by looking at the problem from a different angle.

Another approach

Reducing R6 below 22R brings convergence problems so we will try something else. Altering the ratio between R2 and R5 can have some effect on hysteresis, so we reduce R2. Further Transient analyses show that hysteresis is reduced if we make R2 equal to 750R and there is further reduction by making it 680R. Then the thresholds become 1.33V and 1.09V, and hysteresis is 0.24V, as required. However, the thresholds are both too high by the same amount. We could counter this by increasing Rfix but this means using a non-standard value of 230R. One possibility is to use a preset for Rfix. Another option is to increase R1. Increasing it to 5.1k sets the thresholds to 1.39V and 1.09V. Summing up, the resistance changes needed are R1=5.1k, R2=680R and R6=22R.

In practice we have to recognise that a actual thermistor has a tolerance of 20 percent. The thresholds we have calculated will not hold true for any given thermistor. This means that we must either measure the thermistor we install in the circuit, and repeat the analyses, or perhaps we can substitute preset resistors to allow thresholds to be adjusted to compensate for the inevitable variations.

Temperature sweep

At this stage in the project, it occurred to us that although the resistance of a thermistor changes considerably with temperature, the resistance of all the resistors change to a certain extent. Is this enough to upset the thresholds? Assume that we use inexpensive metal film resistors, which have a temperature coefficient of 200 parts per million per degree Celsius. This can be

specified by adding Tc=0.0002 to each resistor line in the netlist. What about the transistors? The transistors used in our netlist are Spice models, which have temperature coefficients built in. By default, all Spice calculations assume a temperature of 27degreesC for all components (in Kelvin this is a nice round temperature of 300K), and we can investigate effects of other temperatures in one of two ways:

1: We can find out what happens if one or more particular components are at given temperatures. For example, in another circuit we might want to investigate the behaviour of a power transistor running at 100degreesC or more, while the remainder of the circuit is at 27degreesC. This is done by adding Te=100 to its line in the netlist.
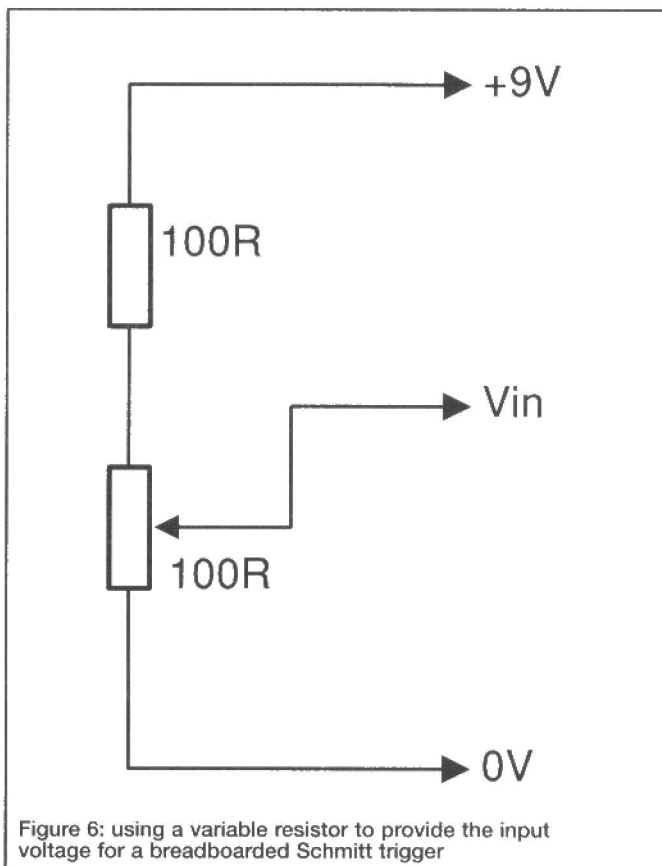
Figure 6: using a variable resistor to provide the input voltage for a breadboarded Schmitt trigger

2: We can sweep all components through a range of temperatures. This is equivalent to taking a breadboarded circuit and putting it in the fridge, the greenhouse, and other places at different temperatures.

The sweep is appropriate for the thermostat circuit, so select Analyses > Tolerance, value and temperature sweeps. On the right, select Temperature, then enter Start = 25.00, Stop = 35.00 and Temperature steps = 3. This will analyse the circuit at 25degreesC, 30degreesC and 35degreesC, spanning its operating range. The result of the Transient analysis is disappointing in the sense that it looks just like an analysis at 27degreesC. The curves for Vin and Vout are identical. In other words, thresholds are constant over the intended operating range of the thermostat. Our design is a success!

PC-based Phonecard reader

Patrick Gueulle has designed a reader that plugs a smart phonecard into a PC and lets you look at the contents programmed within

Being a "smart card" (or "chip card"), the new BT phonecard exerts a real fascination on many enthusiasts: as a collector's item, of course, but also as a very special electronic component (in fact, a highly secured serial eeprom).

Believe it or not, it is quite a simple matter to read the contents of any smart phonecard. An inexpensive, easy-to-build card reader, along with some short pieces of Basic software, can turn any PC into a powerful exploration tool.

The beauty of the thing, however, is that this equipment cannot be used for illegal purposes, such as "refilling" used phonecards.

A phonecard at a glance

Technically speaking, the new BT phone card is a "third

expiry date 09/96

The microchip on a Smart card

generation synchronous smart card". The first generation is the French "Telecarte" (in use since 1983), and the second generation is the early German "Telefonkarte". But most European countries are likely to choose the third generation "Eurochip" card, already in use in Germany, Holland, Switzerland and, last but not least, the UK.

BT began to test the smart phonecard during the summer of 1995 in Portsmouth and the Isle of Wight, but payphones all over the country are now being upgraded.

Many kinds of disposable smart phonecards are of the relatively inexpensive synchronous type, using serial memories with built-in hard-wired security features. In contrast, asynchronous smart cards contain an embedded microprocessor running extremely powerful, often cryptographic, security software. Pay TV cards, cellular phone SIMs and electronic purses such as the Mondex card are the best known examples, but they are of course another story.

Just a flat IC!

A smart card is nothing but a very thin (less than 0.76

Figure 1: The ISO-7816 pinning of the new BT phonecard

iso 2	iso 3	MICRO - INSTRUCTION
1	⎍	RESET
0	⎍	UP

Figure 2: The communications protocol

Figure 3: Schematic diagram

Upon power-up, or more reliably after a reset sequence, the very first bit of the memory array is available for reading on the ISO 7 contact. Every "up" sequence applied to ISO 3 and ISO 2 will then increment the internal address counter and place the next bit onto ISO 7. Figure 2 shows that a low to high transition on ISO 3 resets the card if ISO 2 is high, but increments the address counter if ISO 2 is low.

It must be stressed that "reset" and "up" are the only micro-instructions needed to perform read operations, and that several other more complicated and sometimes top-secret sequences are used to write, erase, and compare bits.

A simple reader

It is a very simple task for even the oldest 8088 PC to output "reset" and "up" sequences on any of its serial or parallel ports, and to sample the I/O output of a synchronous smart card. It was chosen to make use of an RS-232 serial port (COM1:), because enough power is available here to source a good Vcc for the card. However, as RS-232 lines usually carries voltages of plus and minus 12 volts, some clamping is obviously necessary.

Figure 3 shows how three 4.7 volts zener diodes (D3 to D5), two resistors (R2 and R3) and a 78L05 regulator (IC1) are used to solve the problem. R1 is not a current limiting resistor for D3, but a "pull-up" for the "open drain" I/O line of the smart card. D1 prevents any unwanted negative voltage from reaching the regulator (in case of a wrong software command, for example), and D2 allows the connection of an optional 9 volts battery, should an extremely low power RS-232 port have difficulties to generate a good +5 volts (quite unlikely to occur, except on a few battery powered PCs).

A small single-sided PC board layout (figure 4) can easily accommodate such a small number of components, including a DB-9 female connector (CONN 1). The only odd part is the "smart card connector" (CONN 2), of which many makes are commercially available (8 or 16 wiping or landing contacts, NO or NF card detector, etc.)

The "card present" contact of the connector must be of the NO (normally open) type. In other words, it should close itself when a card is fully inserted, so as to apply the power supply to the circuit. The preferred brand is ITT Cannon (see end of article), since the PCB foil was designed according to its pinning, and the PCB supplied by the ETI PCB Service is of this type only. Please note, however, that only the two pins of the "card present" contact usually differ from one make of connector to another. In the UK, Pedoka Ltd. of Hitchin, Herts can also supply a range of smart card connectors from Hyo Sung. They only require a slight modification of the PCB foil.

mm) integrated circuit, accurately mounted on a plastic card about the same size as a credit card. The chip itself, as small as 1 x 1 mm, is hermetically sealed inside.

Siemens is the primary supplier of Eurochip ICs, Philips being a possible second source.

The flat contacts are numbered in accordance with the ISO-7816 standard, as shown on figure 1.

The ISO 5 contact is the ground terminal, the opposite ISO 1 being allocated to the +5 volts Vcc.

Just like any other serial eeprom, a smart card communicates via a data line (ISO 7, usually called I/O), under the control of an external clock signal (ISO 3). A reset input (ISO 2) is also available on this 5-wire bus. ISO 6 remains unconnected on most recent smart cards, since it is reserved for an optional Vpp voltage (as required by the first generation eprom-based smart cards).

Some smart cards come with an ISO 4 contact (located under ISO 3) and with an ISO 8 contact (under ISO 7). Both of them are "RFU" (reserved for future use) and, again, left unconnected on Eurochip cards.

The communications protocol

The useful contents of a smart phonecard consist of a relatively small number of bits.

Figure 4: The component layout for the Smart card reader, using the Cannon CCM01-2NO-3 connector.

Getting started

The only external connection to be made is a standard cable between the female DB-9 of the card reader and the COM1: male DB-9 of the PC. A "monitor extension cable" is suitable, but do not use a "null modem" or any other "crossed" cable. If you choose to build your own cable, just tie pin 3 of a female DB-9 to pin 3 of a male DB-9, then pin 4 to pin 4, etc.

Now, it is time to get one of the new-style BT phonecards, possibly empty, and to type the short SMARTRD.BAS program (figure 5) under GWBASIC or QBASIC. Please note that the "B" value is the base address of the COM1: port. In case of any problem, first check the base address of the actual COM port used, as reported by the BIOS during power-up (or run MSD if Windows is installed).

Figure 5: The Basic "reader" program

```
10 REM — SMARTRD.BAS —
20 KEY OFF:CLS
30 B=&H3F8:REM COM1:
40 PRINT"INSERT A BT SMART PHONECARD INTO READER,
THEN PRESS ANY KEY"
50 IF INKEY$="" THEN 50
60 OUT B+4,0:OUT B+3,64
70 BEEP:CLS:T=TIMER
80 IF T>TIMER-1 THEN 80
90 OUT B+4,1:OUT B+4,3:OUT B+4,1
100 FOR F=1 TO 16
110 FOR G=1 TO 4
120 FOR H=1 TO 8
130 E=INP(B+6) AND 16
140 IF E=16 THEN PRINT"1"; ELSE PRINT "0";
150 OUT B+4,2:OUT B+4,0:NEXT H
160 PRINT" ";:NEXT G
170 PRINT:NEXT F
180 OUT B+3,0
1990 REM (c)1997 Patrick GUEULLE
```

Run the program, insert the card (in the right position) when prompted, then press any key (for example, the space bar). A binary dump will soon appear on the screen, normally looking like the samples in figure 6. It can be hard-copied on the

parallel printer by pressing the PrtScr key. A somewhat different pattern could be displayed, should the card come from another country (including Guernsey) or from a private operator (such as ACC). Anyway, the four first lines of the dump can always be decrypted using the same rules.

Figure 7 shows that the first two lines contain 64 bits of identification data. So called "smart card locks" were designed, by the way, to check them before granting access to, say, a computer or a building. The reason is that part of this ID data is unique for each individual, even empty, phonecard. Small groups of bits are, indeed, the same for all the chips made by the same manufacturer, or for all the cards issued by the same telephone operator. The area from bit 64 to bit 103 is divided into five eight bit "counters". Here, billing units (usually pence in the UK) are stored at the card maker's facility, then erased by the payphones as you phone away. An abacus-like counting scheme allows Eurochip cards to store more than 30000 billing units with just 40 bits of eeprom.

Figure 6a,b and c: How to read the binary dump

```
10101000 00100010 11110111 10011111
10010101 00000000 00000001 10001000
00000000 00000000 00000000 00000000
00000000 11111111 10011111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
```

(a) A sample dump of an empty "new BT phonecard"

```
11011000 00101010 11111111 11001010
01001010 11011010 00101001 10011100
00000000 00000000 01111111 00111111
00001111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
00000000 00000000 00000000 00000000
11110100 10001000 01001010 10101000
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
11111111 11111111 11111111 11111111
```
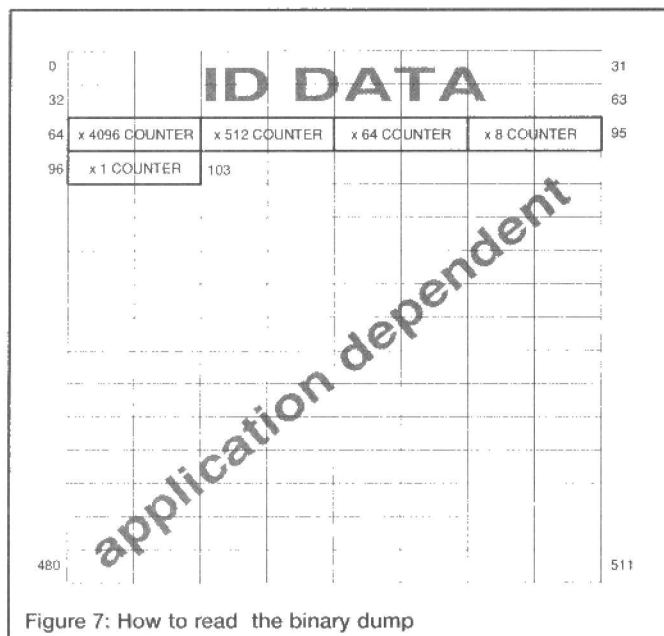
Figure 7: How to read the binary dump

(b) A sample dump of a swiss phonecard (5 F or 500 units left)

```
10010100 00111011 11111111 00000110
01110000 00000000 00000001 11011110
00000000 00000000 00000000 00001111
00001111 11111111 11111111 11111111
10010100 00111011 11111111 00000110
01110000 00000000 00000001 11011110
00000000 00000000 00000000 00001111
00001111 11111111 11111111 11111111
10010100 00111011 11111111 00000110
01110000 00000000 00000001 11011110
00000000 00000000 00000000 00001111
00001111 11111111 11111111 11111111
10010100 00111011 11111111 00000110
01110000 00000000 00000001 11011110
00000000 00000000 00000000 00001111
00001111 11111111 11111111 11111111
```

Resistors
(All 0.25 watt 5 percent)
R1,2,3   8k2 (3 off)

Capacitors
C1   22u 25V radial electro
C2   0.27u polyester, 7.5mm lead spacing

Semiconductors
D1,2   1N 4148 (2 off)
D3,4,5   4.7V 0.25W zener (3 off)
IC1   78L05 positive regulator

Miscellaneous
CONN 1:   90 degree female DB-9 PCB connector
CONN 2:   ITT-Cannon CCM01-2NO-3 smart card connector (with NO contact).
BAT 1 (optional):   9V PP3 battery and flylead connector
PCB

(c) A sample dump of a phonecard from Guernsey (36 pence left)

Bits 96 to 103 are the "x1" counter: here, one bit is changed from 1 to 0 each time a penny (or unit) is spent. As soon as all eight bits are at logic 0, a single bit is set to 0 in the "x8" counter (bits 88 to 95), while the "x1" counter is reset (all bits cleared to 1).

In the same way, a "carry" bit is set to 0 in the "x64" counter when the "x8" counter is globally reset, and so on.

Since the exact value of any new card is pre-loaded into the counters at the factory level, all the counters of an empty card only contain zeros and can no longer be tampered with.

The area from bit 104 to bit 511 is "application dependant". On Eurochip cards like the new BT phonecard, it contains "anti-tearing flags" (a few bits used to prevent any loss of units when a card is removed from the payphone during a call), and various "user areas" usually filled with ones.

Innovative applications are likely to make use of some of them in the near future, such as abbreviated numbers storage, self-dialling numbers, or even a simple electronic purse. Watch for them!

Some locations are also probably involved with the "challenge-response" security scheme of the Eurochip card, but details are obviously top secret!

Do not be surprised if, when trying to read a non-BT phonecard, the resulting binary dump contains the same pattern (locations 0 to 127) four times over. The explanation is that the address counter of older, non-Eurochip cards usually "rolls over" at address 127 instead of 511 .

The SMARTCNT.BAS program (figure 8) just computes the number of billing units available to spend, if any. It might be a help for those collectors wishing to check, at home, the contents of huge lots of phonecards, either from BT or from some other operators.

A very simple algorithm (lines 190 to 240) is called five times for the "x1", "x8", "x64", "x512", and "x4096" counters respectively.

Internal photomicrograph of a Siemens chip inside a Smart phonecard
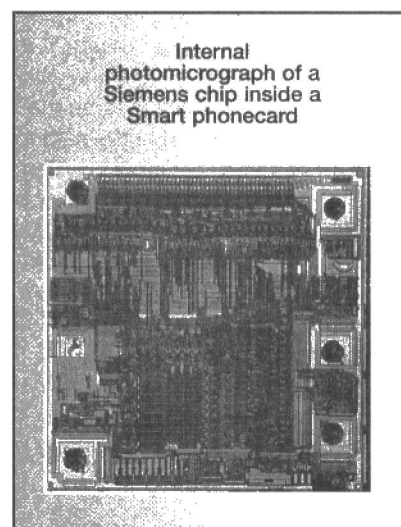
Figure 8: The Basic "counter" program

```
10 REM —SMARTCNT.BAS —
20 KEY OFF:CLS
30 B=&H3F8:REM COM1:
40 PRINT"INSERT A BT SMART PHONECARD INTO
READER, THEN PRESS ANY KEY"
50 IF INKEY$="" THEN 50
60 OUT B+4,0:OUT B+3,64
70 BEEP:CLS:T=TIMER
80 IF T>TIMER-1 THEN 80
90 OUT B+4,1:OUT B+4,3:OUT B+4,1
100 U=0:FOR F=1 TO 63
110 OUT B+4,2:OUT B+4,0
120 NEXT F
```

```
130 A=4096:GOSUB 190
140 A=512:GOSUB 190
150 A=64:GOSUB 190
160 A=8:GOSUB 190
170 A=1:GOSUB 190
180 GOTO 250
190 FOR F=1 TO 8
200 OUT B+4,2:OUT B+4,0
210 E=INP(B+6) AND 16
220 IF E=16 THEN U=U+A
230 NEXT F
240 RETURN
250 CLS:PRINT:PRINT
260 IF U>0 THEN 280
270 PRINT"THIS PHONECARD HAS RUN OUT":GOTO
290
280 PRINT U;"AVAILABLE UNITS (or pence)"
290 OUT B+3,0:PRINT:PRINT:END
300 REM (c)1997 Patrick GUEULLE
```

Of course, do feel free to write your own software for this reader: it should be surprisingly simple now!

The CCM01-2NO-3 connector is available from Electrospeed, Stanstead Road, Boyatt Industrial Estate, Eastleigh, Hants SO50 4ZY. Tel. 01703 644555. Order number 19-12448K. Readers in France may find that their Radiospares Composants catalogue has this connector under the number 160-5224.

For Hyo Sung connectors, enquire at Pedoka Ltd., The Cam Centre, Wilbury Way, Hitchin, Herts SG4 0HG. Tel 01462
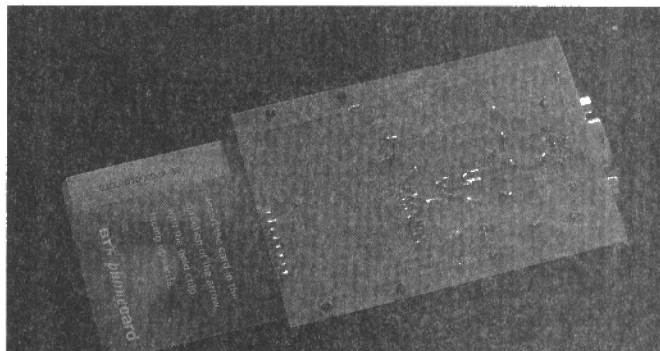
The Smart card reader from the track side
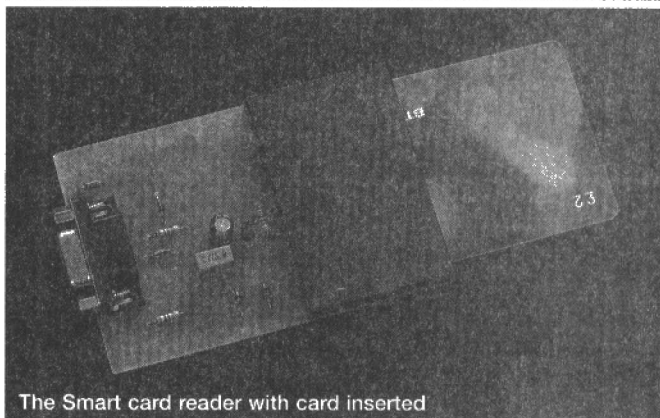
The Smart card reader with card inserted

422433 Fax 01462 422233.

The Cannon PCB provided by the PCB service is the version used to build the prototype. We suggest that you order your connector type before deciding on which PCB variant to follow.

FOILS FOR
THIS ISSUE

High Performance Medium Wave Receiver - Audio board
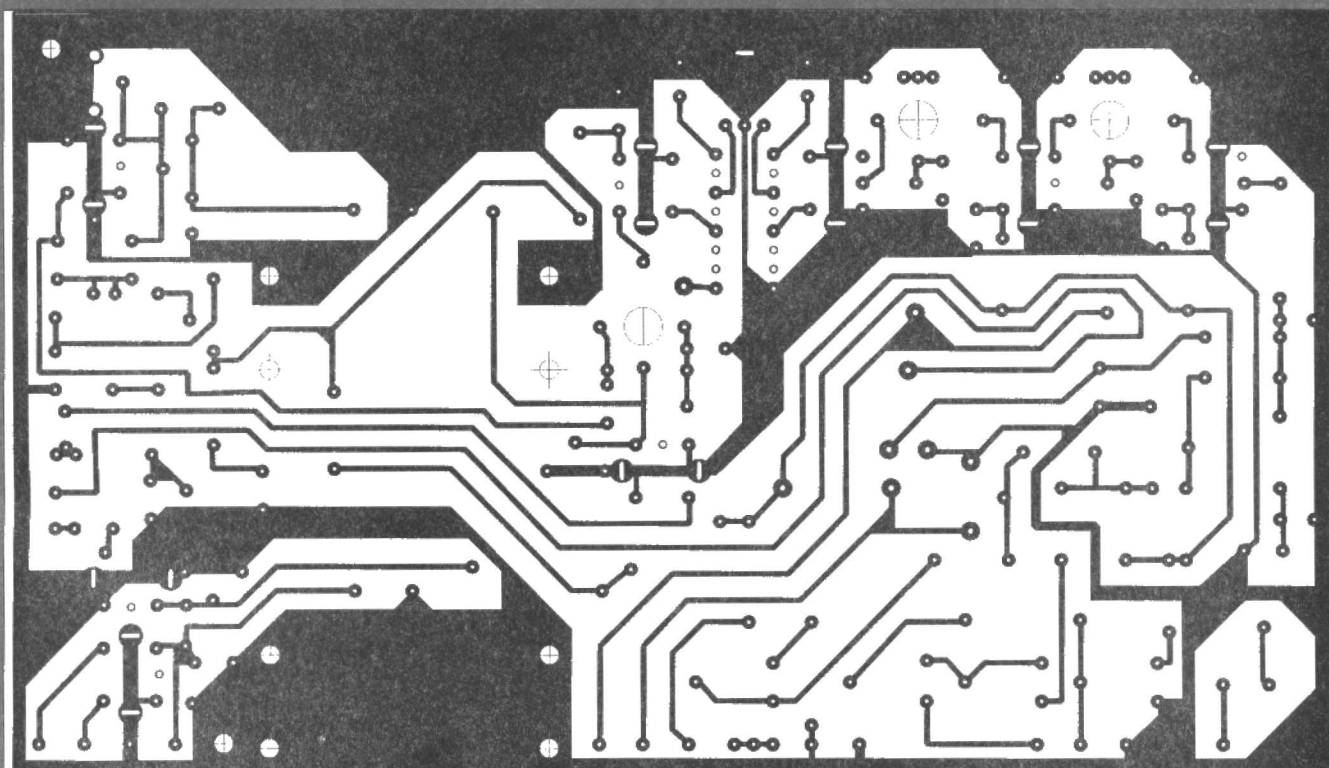
High Performance Medium Wave Receiver - RF board
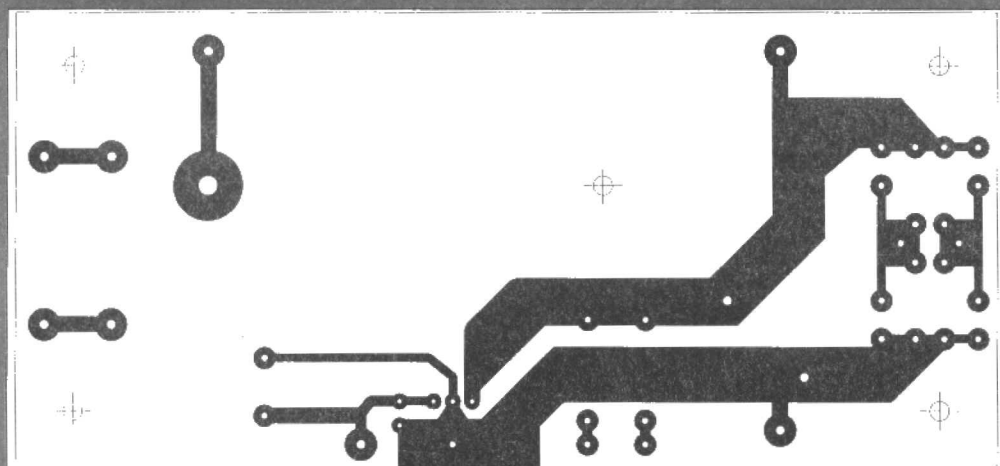
High Performance Medium Wave Receiver - Power supply board
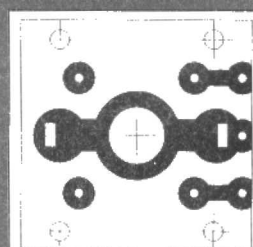
High Performance
Medium Wave
Receiver - Tuning
capacitor board

ETI
ELECTRONICS
TODAY INTERNATIONAL

FOILS FOR THIS ISSUE
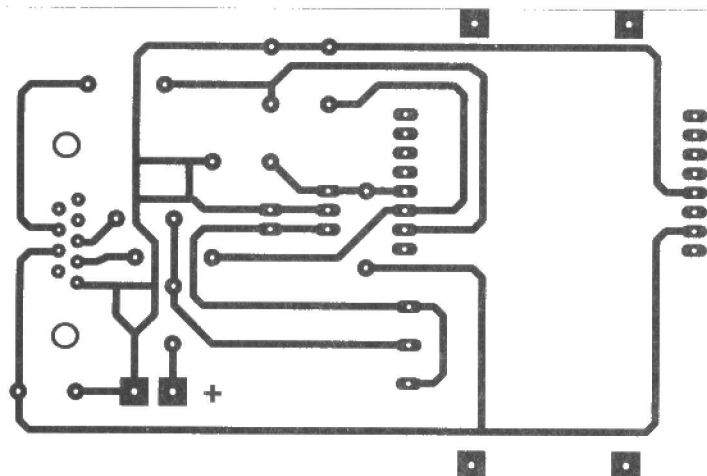
ITT - CANNON ONLY

PC Phonecard Reader
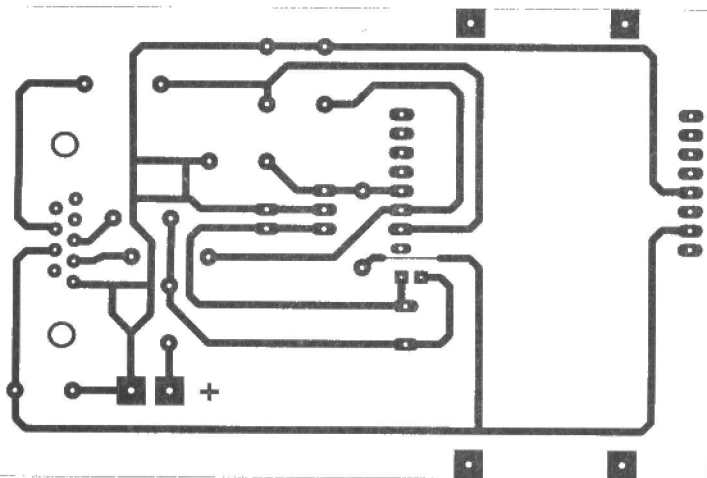
Minute Minder

ITT - CANNON + PEDOKA

MORSE TOUCHKEY (ISSUE 11)

ETI ELECTRONICS TODAY INTERNATIONAL

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Only boards listed here are available from our PCB Service. For past issues of magazines, copy articles or binders, please see the admin panel (page 74) or contact Readers Services (see below) for information.

Name and issue of project	Unit code	Price
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(Due to price breaks there is a small discount on this item.)		
The IQ Tester (previously E/897/20	E/1097/7	£5.64
ETI Issue 9 1997		
Eprom Emulator	E/997/1	£16.49
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The Brake Light Tester	E/897/1	£5.09
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DC Motors: The first Control Unit	E/897/3	£5.09
DC Motors: The 4046 Circuit	E/897/4	£5.09
DC Motors: The Crystal Drive Circuit	E/897/5	£5.09
All three DC Motors boards	E/897/3/4/5	£11.50

ETI Issue 7 1997		
Eprommer: main board (double sided)	E797/1	£13.32
Eprommer: PSU board	E797/2	£5.64
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(double sided):	E797/3	
Any ONE module board		£5.09
Any two modules		£7.90
Any three modules		£11.85
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Practically Speaking

BY TERRY BALBIRNIE

This month we check up on the power rating of a resistor before designing it into a circuit, a necessary procedure to avoid possible overheating later.

We continue looking at some of the calculations needed when developing and testing circuits. This time, we shall look at the topic of power.

The power rating label on a soldering iron

Powerful stuff

Electricity is a form of energy and, as such, can be converted into other types of energy, such as heat (thermal energy) in a soldering iron, light in a bulb, sound in a buzzer, movement in a motor and chemical energy in a charged battery. In electronics work, heat is often unwanted, as when a transistor burns out.

The rate at which energy is converted (how much energy changes from one form into another each second) is called power. A powerful light bulb is coverts electrical energy into heat and light faster than one of lower rating.

Power is measured in watts (W). A bulb rated at, say, 60W is dimmer than one rated at 100W because less energy is converted into light and waste heat in each second. For a given brightness, the modern type of low-energy light bulb needs less power than a traditional filament type. This is because much more energy is converted into light instead of wasting much of it in the form of thermal energy, and the low-energy bulb does not become hot in the way a traditional one does.

When a resistor carries current, the electrical energy is converted into heat and it becomes warm. In many circuits, the power involved is very small and the resistor remains cool. An electric fire heating element is an example of a resistor having a power rating of about 1kW (one thousand watts) and whose sole purpose is to become hot. The filament in a light bulb is another resistor which is designed to become so hot that it glows with white heat and gives out light.

Power rating

As well as its value (expressed in ohms), every resistor has a power rating. This is the maximum power that it can handle without becoming excessively hot. The energy is dissipated by being carried off into the air. It is *essential* never to exceed the power rating of a resistor, and preferably to keep well below it. Typical resistors used in circuits have a power rating of between 0.25W and 1W. The larger component suppliers list resistors with power ratings of 25W or more.

It is often useful to calculate the power which will be dissipated by a resistor to check that its rating will not being exceeded. Doing this before construction work begins will mean that modifications will not be necessary and damage will be avoided.

The formula for the power (P) dissipated by a resistor is:
$$P = I \times V$$
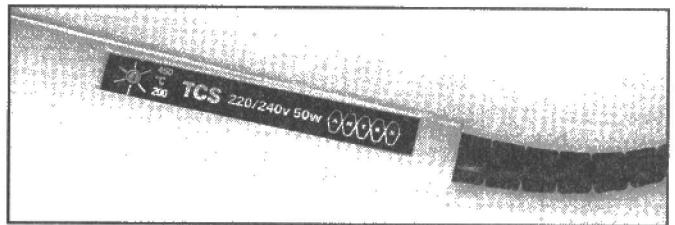
This means that the power (in watts) is equal to the current flowing through it (in amps) multiplied by the voltage across it. Note that if the current is expressed in milliamps, it will need to be converted into amps. This procedure was explained in an earlier part of this series.

Example

Suppose a resistor carries a current of 45mA and is found to have a voltage of 2.7V across it.

$$P = I \times V = 0.045 \times 2.7 = 0.12W$$

A resistor of 0.25W or 0.6W rating would therefore be suitable.

It is straightforward to measure the voltage across a resistor simply by touching the voltmeter probes one on each side of it. However, it is more difficult measuring the current flowing through it. This involves de-soldering one end from the circuit panel and connecting the meter between the free ends. If the value of the resistor is known (and it almost certainly will be, because the colour code will tell you) then there is a trick which enables only the voltage to be measured.

Returning to:

$$P = I \times V$$

Then using Ohm's Law (this topic was covered in an earlier part of this series):

$$I = V/R$$

So: $P = V/R \times V = (V \times V)/R = V^2/R$

Putting this into words, "power is equal to the voltage multiplied by itself and divided by the value of the resistor". Even if your maths is not up to the theory, the method is worth memorising.

If the voltage across a 470W 0.6W resistor is 16V, the power will therefore be 16 x 16 divided by 470 giving 0.54W. The resistor is safe to use but only just. It might be a good idea to use a 1W component instead.

Around the Corner

Sony is striving once again to make the MiniDisc recorder universally popular. Perhaps they will be successful this time. The price of machines has been cut, though it is still more expensive than a low-cost CD player.

The MiniDisc medium is a 2.5-inch electro-optical disc that can hold approximately 140 megabytes of data. This is not enough for a direct digital copy of a whole CD, but a compression system reduces the amount of data to about one quarter required on a CD for the same playing time. The result is a tiny disc, which can record up to 74 minutes of sound. The editorial ears cannot distinguish between MiniDisc sound quality and that of a decent CD player.

To get a full CD duration of sound onto a relatively small storage medium, Sony have used a process involving psycho-acoustic techniques which take advantage of the imperfections of human hearing. Incoming signals are examined and complex calculations are performed to determine which sounds are audible. Rather than record everything in the signal, as DATs (digital audio tapes) do, only the audible signals are encoded, and sounds masked by louder music are omitted.

The system is called ATRAC (Adaptive Transform Acoustic Coding). The compression used by Philips in their DCC system works along similar lines.

To make copies of vinyl albums, the MiniDisc is regarded by many as a better system than analogue audio cassette. Purists may object, but for most people the lack of tape hiss, and the absence of frequency response colouration and slight distortion on normal audio cassettes make the MiniDisc distinctly preferable.

Yamaha and very likely others have used the MiniDisc format to make 4-track recorders. The advantage is that when you use the recorder to "bounce down", the loss of quality associated with multiple generation recordings on audio cassette is much reduced.

Perhaps you have recorded on four separate tracks. You can mix these down on to two tracks. Then you have a stereo pair with the mixdown on it

After much bouncing down, a cassette system can give a slightly ropy sound, while the MiniDisc system is said to suffer much less audible degradation.

The question that occurs is: does the psycho-acoustic coding work for everyone? Possibly there are some golden eared hifi enthusiasts who can hear the difference caused by the compression, but they may not find it easy.

However, to a western listener many Chinese words can be indistinguishable. This is apparently because, when a baby's brain is developing the ability to distinguish sounds, the pathways reinforced in the neural net are those for the sounds heard. Ultimately, some of the pathways are left inaccessible from lack of use, while others, used in the local language, are developed.

Perhaps a native Chinese speaker could hear differences in the sound caused by the compression? Or is the compression algorithm based on how the ear responds to sound, rather than how the brain processes it?

The other question is: Will it catch on? Lack of pre-recorded material will be a drawback, but as MiniDisc is now promoted as a recording medium it may go the same way as audio cassettes - when there were enough users, pre-recorded music became available. If that happens its future is assured.

Quickroute 3.6 and SMART-route competition winners

Quickroute Systems selected Quickroute 3.6 Pro+, Quickroute 3.6 Designer and Quickroute 3.5 Personal as prizes in our August competition (issue 9), as well as copies of SMARTroute 1.0 32-bit autorouter and library packs for the second and first prizewinners. The lucky winners are (first) S J Horton, Folkestone (second) J Gardener, Bristol and D A Larner, Great Yarmouth and (third) S J Brown, Leicester; A McIntosh, Gamelon; G Manson, Thurso; J Capel, Chesterfield; H Kibble, Llandudno and A Hardman, Liverpool.

More information about Quickroute can be obtained from the website www.quick-route. co.uk or from Quickroute's demonstration pack (tel. 0161 476 0202).

Next Month...

Volume 26 no. 13 of Electronics Today International will be in your newsagent on 5th December 1997 ... the leading feature will take a snapshot of the way consumer digital photography is developing ... another shot from Tim Parker's One Shot Timer ... a selection of DC voltage converter circuits from Ray Marston ... Bob Noyes has been working on a switched mode power suppy ... plus all the regulars, and more.
Contents are in preparation but are subject to space and availability.